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ON TWO NEW BEMBROID FISHES FROM THE DEEP SEA OFF MIE PREFECTURE WITH SPECIAL REFERENCE IN RELATION TO HITHERTO KNOWN SPECIES

(*With 3 text figures*)

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In 1876 STEINDACHNER newly described the Bembroid fish, *Bembrops caudimacula* based on a single specimen taken from Nagasaki. Based on several specimens obtained at a spot off the Atlantic coast of North America, GOODE in 1880 described *Hypsicometes gobioides* as a new. In 1893 ALCOCK described *Bathypercis platyrhynchus* as a new species from a specimen collected in the Bay of Bengal. Later, he published "A Naturalist in Indian seas or, four years with the Royal Indian Marine Survey Ship "Investigator" and in this the author pointed out that *Bembrops caudimacula* has a wide but isolated distribution in the seas of Japan, the Bay of Bengal, and off the Atlantic coast of North America, and *Bathypercis platyrhynchus* ALCOCK and *Hypsicometes gobioides* GOODE were synonyms of *Bembrops caudimacula.*

In their review on the Japanese Trachinoid fishes and thier supposed allies, JORDAN and SNYDER considered genus *Hypsicometes* and *Bathypercis* as synonyms of genus *Bembrops*, and reported the condensed original description of *Bembrops caudimacu'a* taken from Nagasaki. But they did not consider *Hypsicometes gobioides* GOODE and *Bathypercis platyrhnchus* ALCOCK to be synonyms of *Bembrops caudimacula* as pointed out by ALCOCK.

In 1913, JORDAN, TANAKA and SNYDER listed *Bembrops caudimacula* of STEINDACHNER (1876). In 1936, KAMOHARA published the supplementary note on the fishes collected in the vicinity of Kôchi, and in this *Bembrops caudimacula* was listed.

He also noted the finding of this fish maturing from eggs during the period from December to February. In 1939, KAMOHARA revised fishes belonging to *Parapercidae* and made a description of *Bembrops caudimacula* taken near Tosa.

The authors are indebted to Dr. N. KURODA who kindly lent us literatures of the above references.

In 1938, OKADA and MATSUBARA published a book entitled "Key to the fish and fish-like animals of Japan" and in this they listed *Bembrops caudimacula* as distributing in the deep sea of south Japan. Later, when publishing "On the off shore bottom-fish of Prov. Tosa, Shikoku, Japan", KAMOHARA included *Bembrops caudimacula.* In 1949, SMITH, J. L. B. published a monograph of the marine fishes from South Africa, and in this he made a description of *Bembrops caudimacula.* He noted in this description that the first dorsal spine is sometimes filamentous which is probably referable to the male and that genus *Hypsicometes* to become a synonym of genus *Bembrops.* In 1950, with publishing "Description of the fishes from Prov. Tosa and Kishyu, Japan," KAMOHARA listed *Bembrops caudimacula* regarding *Bembradon* NYSTROM as a synonym of *Bembrops caudimacula.* In 1951, KURODA examined and sketched an adult specimen (total length 245 mm) taken near Heda, Suruga Bay and compared with figures by GOODE and BEAN (1895), and ALCOCK (1902). By comparing the description of *Hypsicometes gobioides* GOODE and *Bathypercis platyrhynchus* ALCOCK, he believed that they may become synonyms of *Bembrops caudimacula* of STEINDACHNER (1876). Furthermore he considered that *Bembradon laevis* represents the juvenile of *Bembrops caudimacula* and the former species a synonym of the latter.

During the survey of fishes in Mie Prefecture, we had a chance of collecting several *Bembrops* specimens from Owashi Fish Market on 15 Oct. 1950 and 31 March, 1951. Upon our careful examination, the present authors found there exists three distinct forms: one represent *Bembrops caudimacula,* while two others are not previously described.

The following includes not only full descriptions of the two new species but also comparisons are made with *Bembrops caudimacula* and allied species.

Bembrops curvatura, n. sp.

Holotype; a female specimen, measuring 166 mm in total length (No. 1605 preserved in Faculty of Fisheries of the Prefectural University of Mie; type locality Owashi, Mie Prefecture).

D. VI, 14; A. 15; V. 1.5; P. 22; scales in lateral line 47; branchiostegals 7; gill-raker on first arch 3–10; pyloric coeca 3; vertebrae including hypural 28; head 2.56; width of head 5,75; depth 6.0 in body length; snout 3.38; order 4.61; interorbital space 27.0; maxillary 2.7; postorbital part of head 2.0; length of caudal peduncle 4.5; depth of the same 7.71; longest dorsal spine 2.7; longest dorsal spine 2.7; longest soft dorsal ray 2 57; base of first dorsal 3.38; base of second dorsal 1.19; longest anal soft ray 4.15; base of anal 1.13 in head.

Body elongate, subcylindrical, tapering posteriorly. Head rather large,

depressed, longer than twice of depth of body, its width little shorter than half of its length. Mouth large, slightly oblique, maxillary extending beyond the vertical from the anterior margin of orbit, provided with a long skinny flap at its tip, the lower jaw projecting beyond the upper when mouth is closed; the tongue spoon-shaped.

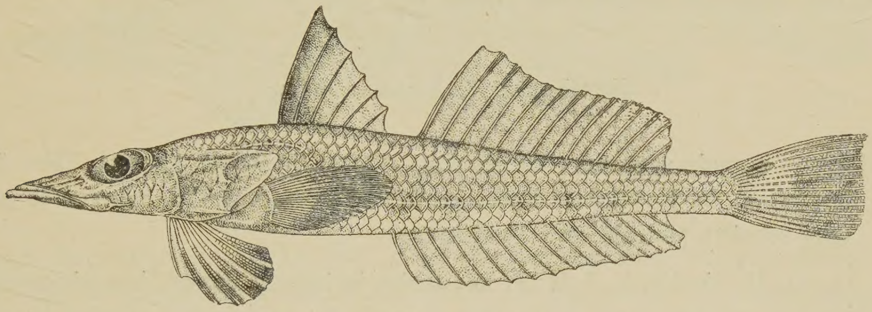

Fig. I. Bembrops curvatura, n. sp. No. 1605, holotype, measuring 166 mm in total length, from off Owashi

Snout elongate, about three times the length of head, much longer than large eye which is equal to the half of the width of head. Opercle thin, with two thin spines; the upper one directing backward and slightly upward, the lower backward. Preopercle with two small spines at the angle.

Teeth villiform; in bands on jaws, vomer, and palatines. Caudal peduncle a little shorter than the length of snout and subequal to the diameter of orbit, its depth subequal two-third of the length. Scales large, ctenoid, deciduous; lateral line descending abruptly in a catenary curve from the tip of opercular flap to the middle region of the body.

First dorsal inserted slightly behind the base of pectorals; the distance from the termination of first dorsal to the origin of second dorsal subequal to the diameter of orbit. This fin composed of six spines, the first spine of which is longest, equal to the length of maxillary. Second dorsal inserted slightly before the origin of anal, the base of second dorsal a little longer than twice the fine-height. Anal inserted under second soft dorsal. Pectorals broad at base, extending beyond the anus and nearly to the vertical from the origin of anal; pectoral rays branched except the first few rays. Ventrals far apart, horizontal, composed of one spine and five branched rays their insertion far forward. The length of ventrals a little shorter than pectorals; the distance from tip of ventrals to anus equal to the length of snout. Gill-raker rather long and slender, the longest one 1.4 times the corresponding gill-lamella. Pyloric coeca long and slender; the longest one extending beyond

the middle of the length of stomach. Stomach V-shaped, moderately elongate, the length is about two times the maximal width.

Peritoneum light brown, roughly punctured with black pigment. Color in formalin light brown, the lateral side of body with four dark brown blotches, dorsal surface of head and snout dark brown. An eye-like black spot on the upper side near the base of the caudal fin.

Bembrops filodorsalia, n. sp.

Holotype: a female specimen, measuring 246 mm in total length. (No. 3346 preserved in Faculty of Fisheries of the Prefectural University of Mie; type locality Owashi, Mie Prefecture).

D. VI, 15; A. 17; V. I. B; P. 27; scales in lateral line 64; branchiostegals 7; gill raker on first arch 3–13; pyloric coeca 3; vertebrae including hypural 28; head 2.62; width of head 5.85; depth 8.15 in body length; snout 2.79: orbit 5.06: interorbital space 27.0; maxillary 2.7; postorbital part of head 2.25; length of caudal peduncle 4.5; depth of the same 7.36; longest dorsal spine 1.76; longest soft dorsal ray 3.52; base of first dorsal 3.68; base of second dorsal 1.17; longest soft anal ray 6.23; base of anal 1.69 in head.

Body elongate, subcylindrical, gradually becoming narrower. Head rather large, depressed, longer than three times depth of body its width little shorter than half of its length. Mouth large, slightly oblique, the maxillary slightly extending beyond the vertical from the anterior margin of orbit, provided with a rather long cutaneous flap at its tip, the lower jaw projecting beyond the upper when mouth is closed; the tongue spoon-shaped.

Snout elongate, about three times of the length of the head, much longer than large eye which is much about to the half of the width of head. Opercle thin, with two thin spines; the upper one directed backward and slightly upperward, the lower backward. Preopercle with one small spine at the angle.

Teeth villiform; in bands on jaws, vomer, and palatines. Caudal peduncle much shorter than the length of snout and subequal to the diameter of orbit, its depth subequal two-third of the length. Scales rather large, ctenoid, deciduous; lateral line curving down smoothly over pectorals and running directly backward. First dorsal inserted sligtly behind the base of pectoral, the distance from the origin of second dorsal to the termination of first dorsal subequal to the diameter of orbit.

This fin composed of six spines, the first of which is longest and filamentous, equal to one and half of the length of maxillary. Second dorsal inserted slightly before the origin of anal, the base of second dorsal a little

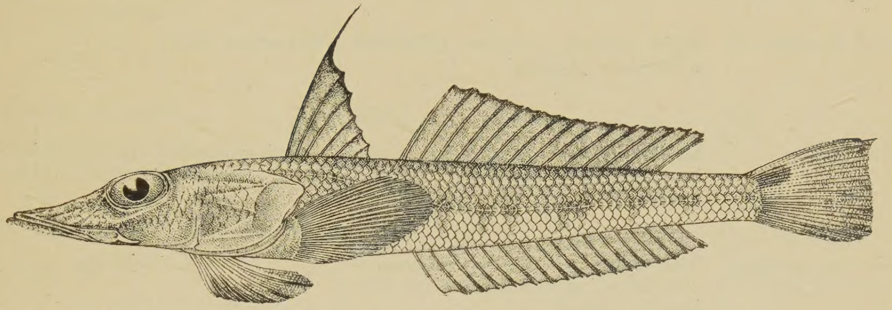

Fig. 2. Bembrops filodorsalia, n. sp.: No. 3346, holotype, measuring 246 mm in total length, from of Owashi.

longer than twice the fin height. Anal inserted under second soft dorsal ray, the base of anal shorter than the base of second dorsal. Pectorals broad at base, extending beyond the anus and nearly to the vertical from the origin of anal; pectoral rays branched except the first few rays. Ventrals far apart, horizontal, composed of one spine and five branched rays, their insertion far forward. The length of ventral shorter than pectoral; the distance from tip of ventral to anus subequal to the length of snout.

Gill raker rather long and slender, the longest one equal to the corresponding gill-lamella in their length. Pyloric coeca long and slender, the longest one extending beyond the middle of the length of stomach. Stomach V-shaped, elongate, the length is about four times the maximal width. Peritoneum brownish black.

Color in life greyish brown, the lateral sides of body and the opercular flaps with many yellowish green spots. A fine eye like dark spot on the upper side near the base of the caudal fin. Front half of first dorsal dusky.

Color in formalin greyish brown, the lateral side of body with several dark brown blotches. An eye like black spot on the upper side near the base of the caudal fin.

Remarks: These two new species bear close resemblances to *Bembrops caudimacula* in general appearance but they differ by having the characteristics analysed in the following tables.

Species / Items	*B. curvatura*	*B. caudimacula*
Direction of lateral line	Lateral line descending abruptly in a catenary curve from a tip of opercular flap to the middle of body and running directly back ward	Lateral line curving down smoothly over pectoral and running directly backward

Peritoneum	Light brown, roughly punctured with black pigment	Brownish black.
Stomach	Moderately elongated, the length is about two times the maximal width	Much elongated, the length is about four times the maximal width
Ventral appearance of head	The region where articular bone is articulated with dentary bone, projecting inward	Not projecting
Anal fin	15 rays	16 rays

Bembrops filodorsalia is also referable to *Bembrops caudimacula* in the direction of lateral line, peritoneum, stomach, and the ventral appearance of head, but differs from it in the following characters.

Species / Items	*B. filodorsalia*	*B. caudimacula*
Scales in lateral line	60–64	42–53
First dorsal spine	Filamentously tapering	Not filamentous
Second dorsal fin	15 rays	14 rays
Pectoral fin	26–28 rays	24 rays
Anal fin	17 rays	16 rays

Perhaps the two new species seems to differ from *Hypsicometes gobioides* of GOODE (1880) and *Bathypercis platyrhynchus* of ALCOCK (1893), which were regarded as synonyms of *Bembrops caudimacula*. In the direction of lateral line, *Bembrops curvatura* differs from *Bathypercis platyrhynchus*, but agrees with *Hypsicometes gobioides*. Though *Bembrops curvatura* is in accordance with *Hypsicometes gobioides* in the direction of lateral line, the former species differs from the latter in several characters as given below.

Items \ Species	*B. curvatura*	*H. gobioides*
Scales in lateral line	45–47	65
Soft dorsal ray	14	15–17
Anal ray	15	16–18
Pectoral ray	22–24	26

Furthermore, *Bembrops curvatura* differs from *Bathypercis platyrhynchus* in the number of anal rays in addition to the difference in the direction of lateral line. Namely, the present species has 15 rays but *Bathypercis platyrhynchus* has 16 rays.

Bembrops filodorsalia agrees with *Bathyp:rcis pla!yrhynchus* in the direction of lateral line. But the former species is distinguished from the latter in having the following characters.

Items \ Species	*B. filodorsalia*	*B. platyrhyuchus*
First dorsal spine	Filamentously tapering	Not filamentous
Second dorsal fin	15 rays	14 rays
Anal fin	17 rays	16 rays
Scales in lateral line	60–64	45

Discrepancy from *Hypsicometes gobioides* is made by the direction of lateral line and the filamentous dorsal dpine.

Moreover, the two new species resemble to *Bembradon laevis* NYSTROM (1887), which was recently regarded as a synonym of *Bembrops caudimacula* by KAMOHARA and KURODA, but differ from it by having the following characters.

Items \ Species	*B. curvatura*	*B. filodorsalia*	*Bembradon laevis*
Scales in lateral line	45–47	60–64	40
Anal fin	15 rays	17 rays	16 rays

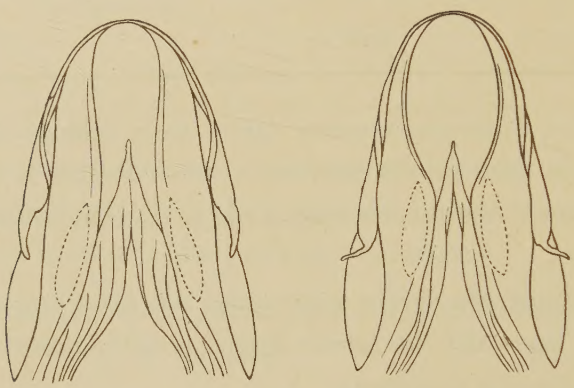

Fig. 3. Ventral appearance of head.
Right: Bembrops curvatura, n. sp.
Left: Bembrops filodorsalia, n. sp.

Supplementary note: Alcock (1902) and Kuroda (1951) regarded *Hypsicometes gobioides* as a synonym of *Bembrops caudimacula*. But the present authors propose that the obvious differences between the two can be made in the direction of lateral line, number of scales in lateral line, rays of second dorsal fin, rays of anal fin, and rays of pectoral fin, so we regard them to be two distinct species.

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A NEW BLENNOID FISH FROM THE SEA OF JAPAN

(*With 1 text-figure*)

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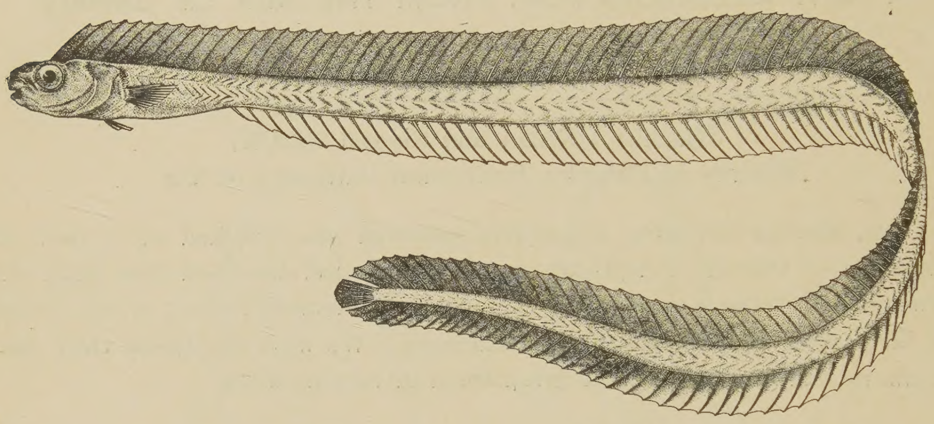
In May of this year, a complete specimen was obtained at a spot off the coast of Owashi, a depth of about 150 hiro and described here under the new name of *Xiphasia matsubarai.* This species is named in honor of our friend, Dr. KIYOMATSU MATSUBARA, Kyoto University. We wish to express their gratitude to him for his kindness given them in various ways.

Xiphasia matsubarai, n. sp.

D. 112; A. 101; P. 11; V. 3; C. 10.

Head 14.8 in body length; depth just back of the head 28.2; same at the anus 38.1; distance between the tip of snout and the origin of anus 6.9. Snout 4.8 in head; eye 3.8; interorbital space 3.8; preorbital part of head 1.9; length of upper jaw 3.8; pectoral 2.4; ventral 3.2; longest dorsal ray 1.6; longest anal ray 1.7. Body elongate and slender; compressed, especially on the head and trunk; wholly naked. The ventral outline of body gradually ascended from base of pectoral to anus and the maximal depth of body measured at the posterior margin of head. Tail much longer than head and trunk, and its length is 85.8 % of the body length; and becoming band-like posteriorly. Head oblong, subquadrangular, nearly as long as trunk, its depth a fifth greater than its width and 1.9 times in the length. Mouth horizontal small, maxillary slightly extending beyond the anterior margin of eye; snout blunt, its horizontal length slightly shorter than diameter of eye; eye rather large, circular, lateral, high up, its diameter little shorter than snout; interorbital space flat, its distance equals diameter of eye. Teeth in jaws subconical, close together; these in lower jaw longer and more curved than upper jaw. Posteriorly to the row of teeth in lower jaw is a pair of relatively enormous, strong, sharp, backward curved canines, their length two-fifths of eye diameter. Gill-membranes continuos, free from isthmus, forming a broad fold across it. Origin of dorsal fin situated vertical above the middle point of eye; gradually

increased in its height measured before the posterior end of the half of body. Number of the rays composed dorsal fin 112, slender and delicate. Anal fin



Xiphasia matsubarai, n. sp. No. 4052, holotype, measuring 282 mm in standard length, from off Owashi.

inserted under the 13 dorsal ray, the first ray about 0.14 times and the longest ray about 0.58 times of head; its greatest height measured about the second thirds of the base of fin. Number of rays composed the anal fin, 101, slender and delicate. Pectoral fin rather short, 2.4 times in distance from the origin to anal fin and reaches to under the base of seventh dorsal ray. It composed eleven rays, delicate, unbranched. Ventral fin jugular, inserted under the base of the fourth dorsal ray. It composed three rays. The caudal fin truncate, with no elongate ray, and composed about ten rays.

Color in formalin uniformly light chocolate, small blackish spots dotted on the body and vertical fins. Dorsal and anal fins are black on account of spots more densely dotted and the posterior part of anal fin is also black, while the anterior larger part, sparsely dotted along the base, whitish. Pectoral and ventral fins whitish.

Described and figured from a specimen, No. 4052 preserved in Faculty of Fisheries of the Prefectural University of Mie, measuring 288 mm (body length 282 mm).

Remarks: The present species is closely related to *Xiphasia setifer* SWAINSON in general appearance but it differs by having the characteristics analysed in the following table.

Species / items	*Xiphasia Matsubarai*	*Xiphasia setifer*
Number of dorsal rays	112	125–129
Number of anal rays	101	110–116
Origin of dorsal fin	situated vertical above the mid le point of eye	situated before the eye
Two central caudal rays	not elongated	much elongated

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COPEPODS PARASITIC ON JAPANESE FISHES

1. ON THE SPECIES OF CALIGUS AND LEPEOPHTHEIRUS

(*With 14 Text-figures*)

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Our present knowledge on the parasitic Copepods from Japan principally owes to the excellent works of S. YAMAGUTI. In his series of papers published in 1936 and in 1939, he dealt with 116 species infesting the fishes besides those found on the Molluscan hosts. Up to his time, about 30 species had been reported from our country by SHISHIDO (1898), ISHII (1916), WILSON (1922), HARADA (1930), TOKIOKA (1936) and others. As YAMAGUTI's contributions contained some of those already recorded, there are, at present, more than 130 piscicola Copepods known to occur in our waters.

The few years since, I have made my effort to gather the Crustacean parasites of fishes chiefly on and off the coast of Mie Prefecture. Supplemented by those forwarded through the courtesy of the colleagues in my former and present appointments, the specimens in my hand have come up to about 150 lots. Out of these, some of the Cymothoids found in the buccal cavities of fishes were reported last year in the Bulletin of the Japanese Society of Scientific Fisheries, vol. 14. As regards the Copepod parasites, these will be described in a series of papers which are to be published from now on, in case they are either new to science or to Japan, or they are considered worthy of an account for some other reasons. In the following pages, I shall give full descriptions on four species of *Caligus* and on the same number of *Lepeophtheirus*. Of these, *C. epinepheli* YAMAGUTI and *L. uenoi* YAMAGUTI are recorded regarding their newly found males, *L. goniistii* YAMAGUTI is for having been taken from several fishes other than original host as well as for the discovery of juvenile forms, and all the remainders represent each a new species.

A number of the specimens here dealt with were placed under my examination through the kindness of Dr. K. KURONUMA and Mr. K. OOYAMA to whom I wish to express my gratitude. I am also grateful to Dr. S. YAMAGUTI for

accomodating me some of the literature. The present study was carried out with the aid of grant from the Science Research Fund of the Department of Education to which my sincere thanks are due.

Genus Caligus Müller 1785

Caligus epinepheli Yamaguti 1936

(Figs. 1 & 2)

C. epinepheli Yamaguti 1936. Parasitic Copepods from Fishes of Japan, Pt. 2, Caligoida, pp. 4–5, Pl. III, figs. 27–39.

Measurements in mm.

	Body	Carapace	4th thoracic segment	Genital segment	Abdomen		Egg string
Female	2.98	1.25×1.07	0.12×0.24	1.02×0.83	0.56×0.22		1.58
Male	2.29	1.23×1.04	0.10×0.24	0.59×0.39	1st seg. 0.15×0.17	2nd seg. 0.24×0.18	

Female (Figs. 1, A, C, D & 2): Whitish in alcohol, without pigment.

Carapace ovate, a little longer than wide. Frontal plate prominent, with a narrow flange. It has a median excavation, on either side of which it is broadest and narrows towards lateral ends. Lunules circular, lying close together. Lateral margin evenly round, bordered with a narrow flange. Cross-bar of the H-shaped dorsal groove only slightly arched. Post-median lobe a little more than half the entire width, slightly extending beyond lateral lobes, and with border widely rounded, but more or less uneven at lateral angles. Posterior sinus deep and narrow, somewhat inclined to the median axis posteriorly. Fourth thoracic segment small, confluent with succeeding one. It is wider than long, strongly narrowed in front of and behind the limb bases, where it forms angular point on either side. Genital segment very large, longer than wide, about 1/5 shorter than carapace, flask-shaped, having antero-lateral corners gracefully round and contracted into a short waist to join the foregoing segment; 2 sides somewhat divergent backwards, continuing well-round lateral angles, between which the posterior border is slightly concave. Abdomen 1-segmented, elongate, cylindrical, about half as long as foregoing segment, and truncate posteriorly.

First antenna has basal joint plentifully supplied with plumose hairs on anterior border and distal joint tipped by simple setae. Terminal hook of 2nd antenna sharply bent near the tip, and basal spine blunt. Maxillary hook relatively large, well-curved; second maxilla a short single spine issued from

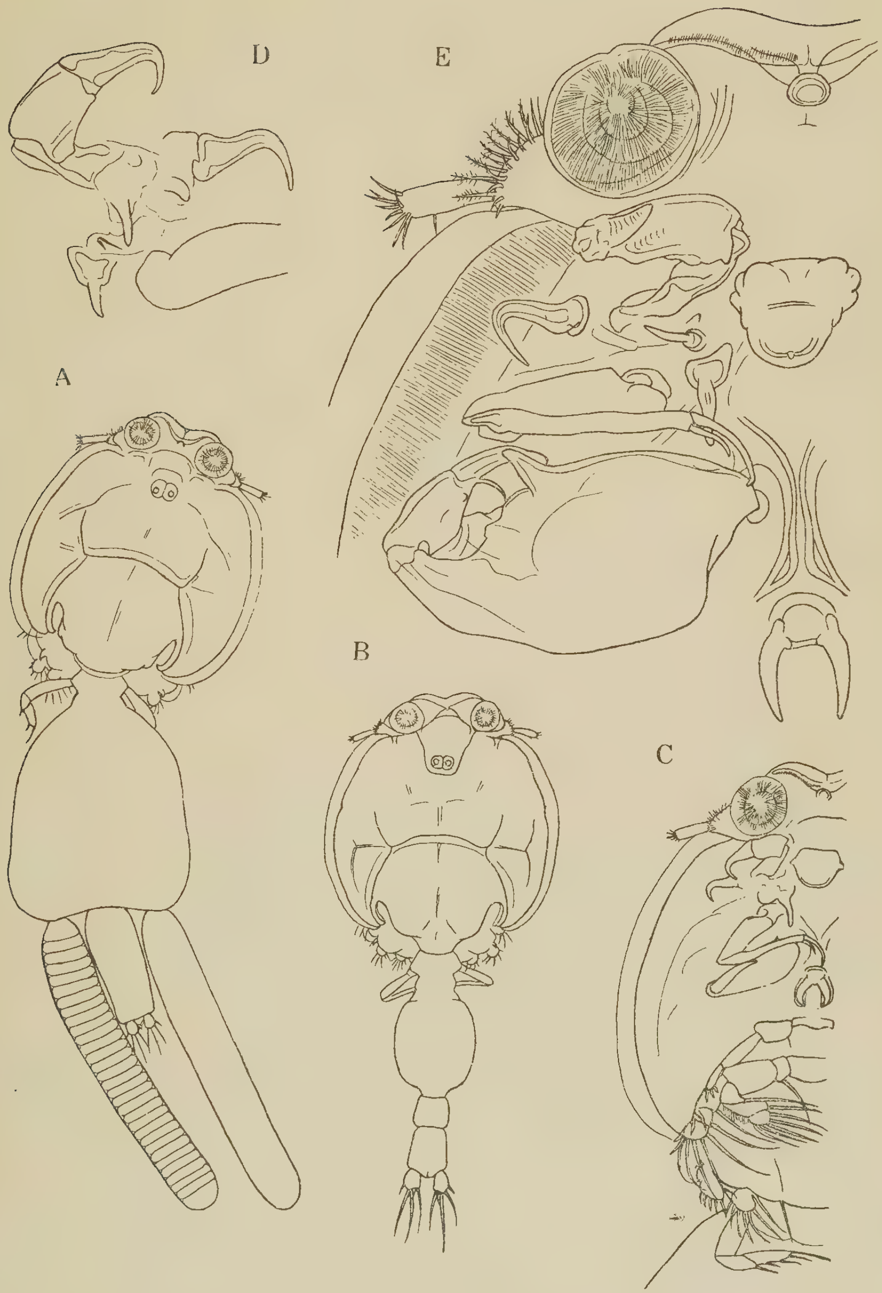

Fig. 1. *Caligus epinepheli* Yamaguti. A, female, dorsal view; B, male, dorsal view; C, female, ventral view of carapace; D, female, 2nd antenna with maxillae; E, male, anterior part of carapace, ventral view. A, B ×27, C ×42, D, E ×123.

a broadened base. Apical joint of 1st maxilliped almost straight, longer than the basal and with a triangular lamina at a short distance behind the tip; 2 apical spines unequal, with narrow rims along their borders. Second maxilliped with its proximal joint moderately swollen, and the distal well curved, sharpened apically, bearing a seta at about the center. Sternal fork the shape of a V, with branches curving at the tip inwards and fringed by narrow flanges.

Arrangement of spines on the pereiopoda are shown in the following table:*

Pereio-pod	Border	Proto-podite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer	1P	1rh	3H, 1P				
	Inner	1P, 1H	C					
II	Outer		f, 1H	1H	1H	c	C	
	Inner	f, 1P, 1s	c, 1P	1P	6P	1P	c, 2P	6P
III	Outer	f, 1h	1H	1h, c	c, 3h		c, 1h	
	Inner	f, 1P		1P	4P	1P	5P	
IV	Outer	1P	1H	4H				
	Inner			1h				

First pereiopod has a blunt spine at inner distal angle of basal joint, a row of minute cirri on inner margin of 2nd, and 3 claws besides a thinner plumose spine on the top of 3rd, but lacks longer ones of inner border. Second limb provided with a rather broad flange on inner side of protopodite as well as along transverse bar combining limb bases of both sides and with a narrower flange on outer border of 1st joint of exopodite. First 2 joints of exopodite bear a rimmed spine at outer distal corner, while the 3rd has 2 blunt, winged spines, the distal one being ciliated along inner border. Outer border of 2nd joint of endopodite hemmed with a narrow lamina which is fringed by a row of setae stiffer than those found on the other side. Protopodite of 3rd pereiopod furnished with broad flange on outer and inner borders; the spines carried by the 2 rami far shorter than those in foregoing limb and basal hook of exopodite unguiform, not being crooked. Fourth pereiopod thickset, 3-jointed; 1st joint longer than others combined, with a short plumose hair at outer distal angle, 2nd with a single rimmed spine and 3rd with 4 of such spines, one in the middle of outer border and 3 at the end, besides a minute spur at inner distal angle of this joint. Rudiment of

*Abbreviations in the tables: C, row of cirri c, row of cilia; f, chitinous flange of segment margin; H, long spine; h, short spine; P, long plumose spine; p, short plumose spine; rh, rudimentary spine; s, single seta. Numerals indicate the number of spines or setae.

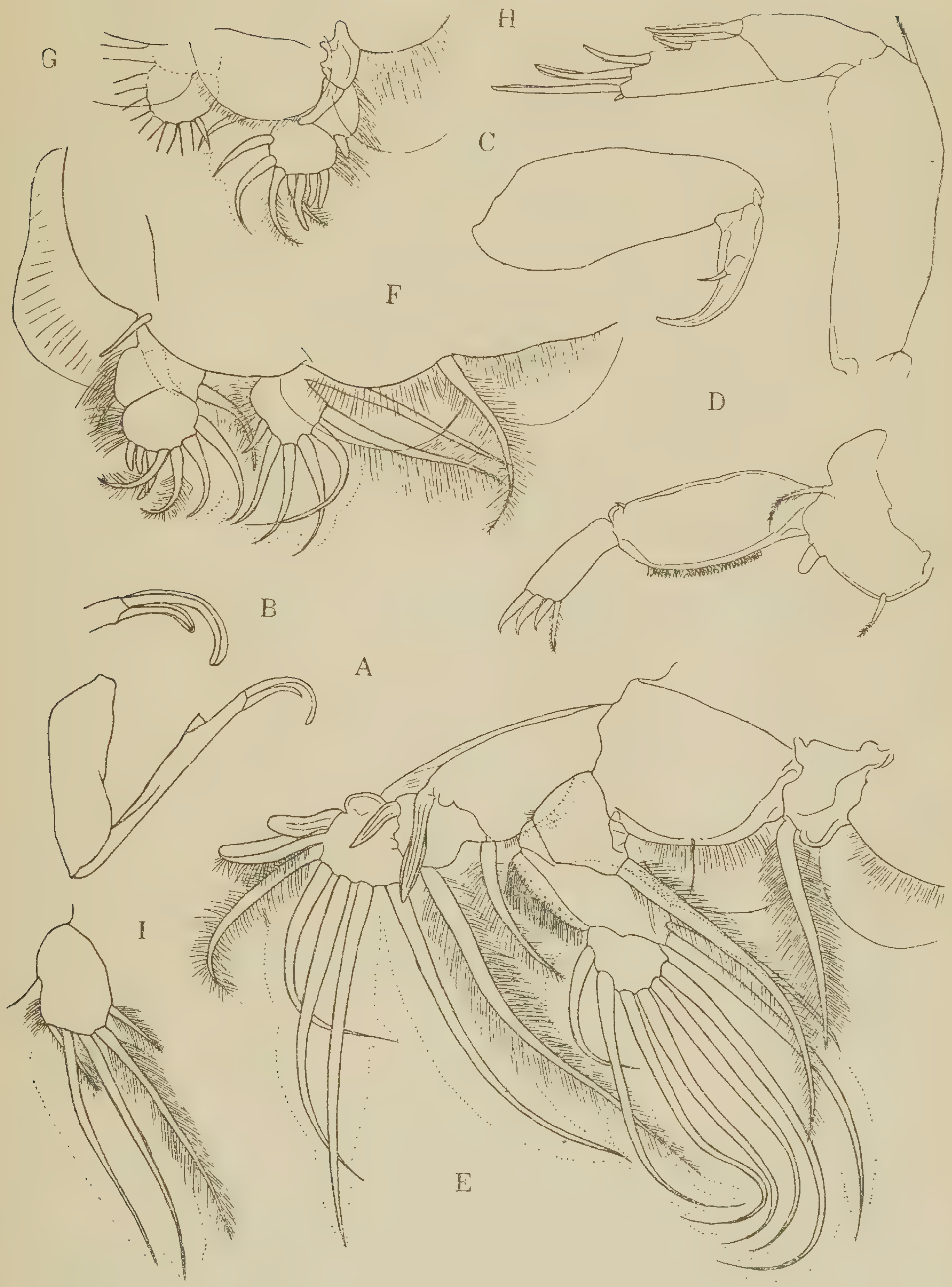

Fig. 2. *Caligus epinephcli* Yamaguti, female. A, 1st maxilliped; B, tip of same; C, 2nd maxilliped; D, 1st pereiopod; E, 2nd pereiopod; F, 3rd pereiopod; G, same, inner view; H, 4th pereiopod; I, caudal ramus. A, C ×123, B, D–I ×174.

5th pereiopod wanting. Caudal ramus short, terminating in 3 long plumose spines and 2 much shorter ones, lying one on each side of them.

Male (Fig. 1, B, E): Much shorter than female, whitish, without pigment.

Post median lobe of carapace evenly round on sides, but on midline with a wedge shaped, small projection extending far beyond lateral lobes. Fourth thoracic segment coalescent with succeeding one and resembling that of female in shape and size. Genital segment relatively smaller than in other sex, half as long as carapace, 1.5 times longer than wide, with round lateral borders, but narrowed in front into a waist having zigzag sides. Abdomen 2-segmented, 1/3 as long as carapace; 1st segment squarish, 2/3 as long as the 2nd, which is longer than wide and has posterior border produced in the middle.

First antenna more or less rugose on surface owing to the presence of parallel ridges; apical joint spatulate, with an acuminating but blunt tip and reflected over the proximal; basal spine long. Second maxilla dactyliform, relatively longer than in female. Second maxilliped subchelate, with basal joint enormously inflated and bearing a strong triangular process at inner distal angle. Apical joint a strong claw terminating in a blunt tip, and with a tubercle besides a seta about the middle. Otherwise as in female.

Occurrence: On the gills and within buccal cavity of *Sparus macrocephalus* (BASILEWSKY) at Momotori, Mie Pref. 8 females and 6 males.

Remarks: The present specimens are in accord with the type in every particular of structure. But, unlike the type, the abdomen is not segmented. Wilson (1905) pointed out on several occasions that the line of articulation on the abdomen of Caligoida is liable to disappear by the fixation with alcohol. It is rather probable that alcoholic specimens of mine have lost the segmentation which otherwise ought to be present. This is the first record of the male form, which was not discovered in the original specimens taken from *Epinephelus akaara*.

Caligus oviceps n. sp.

(Figs. 3 & 4)

Measurements in mm.

	Body length	Carapace	Width of post-median lobe	4th thoracic segment	Genital segment	Abdomen
Female	3.41	2.30×2.00	1.04		0.82×1.07	0.30×0.28
Male	3.78	2.37×2.07	0.93	0.30×0.44	0.52×0.59	0.48×0.26

Female (Figs. 3, A, & 4, I–K): Whitish in alcohol, sparsely spotted with dendritic pigments only on ventral surface.

Carapace ovate, 2/3 as long as body, longer than wide, and widest on the level of posterior quarter of its length. Frontal plate notched on the median, furnished with lunules. Lateral margin evenly round, with a broad flange. Post-median lobe about half the entire width, with widely round posterior border, and extending a little beyond lateral lobes. Posterior sinus deep and narrow, parallel with the central axis. Cross-bar of the H-shaped dorsal groove strongly arched anteriorly, dividing the longitudinal grooves into shorter anterior and longer posterior arms. Fourth thoracic segment fused with the genital, without remaining any trace of articulation. The composite segment wider than long, a cordiform, narrowing anteriorly into a short neck to join the carapace; lateral sides well round, but with an insignificant protuberance on either side of the base of the neck where 4th pereiopoda are inserted, and slightly produced at post-lateral angles as short, round lobes bearing 2 setae. Abdomen rather small, nearly as wide as long and less than 1/3 the length of foregoing segment from which it is distinctly bordered. It is rectangular in shape but with an oval median tubercle on posterior side.

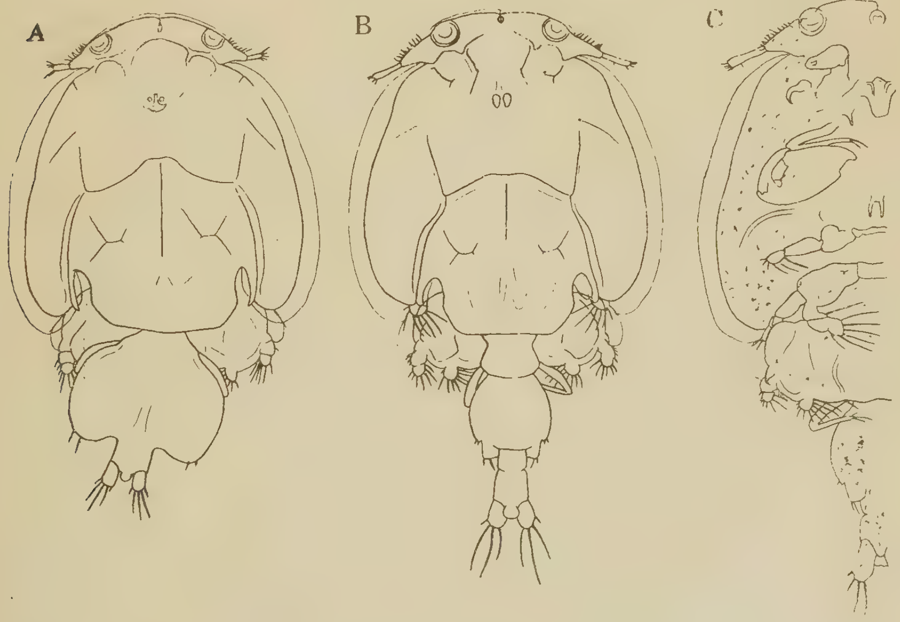

Fig. 3. *Caligus oviceps* n. sp. A, female, dorsal view; B, male, dorsal view; C, male, ventral view. A, B ×18, C ×21.

First antenna small, with distal joint shorter than the basal. Terminal claw of 2nd antenna somewhat bent in S-form with its apex undivided; basal spine blunt and dactyliform. First maxilla a little longer and stouter than antennal claw, scarcely curved at the apex. Second maxilla reduced into a single spine and with a short seta in front of its base. First maxillipeds relatively small, terminal joint being longer than the basal and provided with a triangular lamina at a short distance behind the tip, which bears 2 short spines. Second maxilliped feeble; basal joint slender, with its calibre not exceeding 1/5 the length even in the thickest region; terminal claw also slender, half as long as the former, rather straight ending in a sharply pointed tip, and with a minute seta. Sternal fork with branches slightly divergent, interposing a wedge-shaped space between them.

Arrangements of spines on the pereiopoda are shown in the following table:

Pereiopod	Border	Protopodite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer		1s	3h				
	Inner	1s	c	3P				
II	Outer		1H, f	1H	1p			
	Inner	1P	1P	1P	6P	1P	2P	6P
III	Outer	f	1H	1h, c	3h, c	c	c	
	Inner	1P, c, 1s	1P	1P	4P	1P	6P	
IV	Outer			1H	4H			
	Inner							

First pereiopod has apical claws on 3rd joint reduced into 3 feeble setae. In 2nd pereiopod, 1st joint of exopodite bears a narrow flange on the external border, and 3rd joint carries a short plumose spine outside the ordinary longer 6. Third pereiopod provided with a broad lunular flange on outer margin of protopodite and a simple basal hook on exopodite; both rami apart from each other. Fourth pereiopod small and slender, with 1st joint longer than other 3 put together; border between 2nd and 3rd joints runs in an unusual direction from the outer proximal towards the inner distal; 2nd joint without spine, while 3rd with 1, 4th with 2 longer spines interposed between 2 shorter ones. Fifth pereiopod absent. Caudal ramus short, surmounted by 3 plumose spines besides 2 shorter simple setae, one on each side of them.

Male (Figs. 3, B, C, & 4, A–H): Longer than female, with pigment spots.

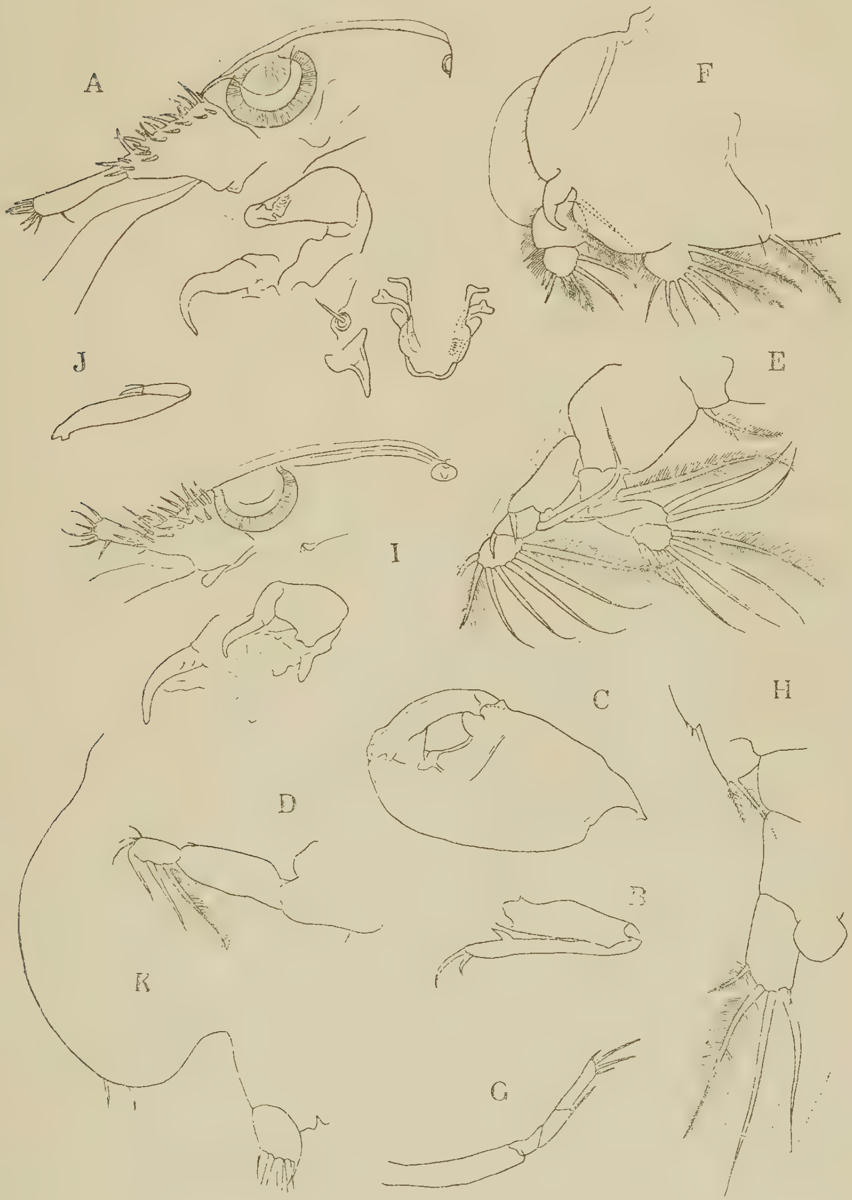

Fig. 4. *Caligus oviceps* n. sp. A–H, male; A, cephalic region, ventral view; B, 1st maxilliped; C, 2nd maxilliped; D, 1st pereiopod; E, 2nd pereiopod; F, 3rd pereiopod; G, 4th pereiopod; H, post-lateral angle of genital segment with abdomen, dorsal view. I–K, female; I, cephalic region, ventral view; J, 2nd maxilliped; K, genital segment with abdomen, ventral view. A–F, H–K ×58, G ×72.

Carapace 5/8 as long as body, slightly broader than in female and with frontal plate somewhat more depressed. Post-median lobe reatively narrower, less than half as wide as carapace, with margin nearly straight, obliquely truncate at lateral angles and extending much beyond lateral lobes. Posterior sinus wider and cross bar of the H-shaped dorsal groove arched not so much as in female. Fourth thoracic segment distinct from the succeeding, with length 1/8 that of carapace, shorter than its own width, and somewhat constricted behind the anterior end. Genital segment about 2/7 as long as carapace, nearly as long as wide, a barrel-shape having round sides, but bearing a pair of quadrangular lobes at post-lataral angles. Abdomen elongate, but shorter than genital segment and indistinctly separated into 2 segments; 1st segment shorter than the 2nd which bears an oval median tubercle on posterior side.

First antenna much longer and stouter than in female, with distal joint attaining twice the length of that of this sex. Terminal joint of 2nd antenna robust and thick, with its tip strongly curved so as to turn back over its main part and split into 3 dactyli, against which it bears further a truncate lobe having a file-like surface. Maxillary hook more strongly crooked than in female. Second maxilliped subchelate; palm enormously inflated, furnished on anterior border at some distance beyond the center with large denticles crowded together; distal border depressed leaving an oval space between itself and thick curved finger, even when it is appressed to the palm. Angular post-lateral lobes of genital segment probably indicative of 6th pereiopod and surmounted by 2 short plumose setae. Rudiment of 5th pereiopod appears to be represented by a small cirri-tipped process in front of the 6th. Caudal ramus terminating in 3 long plumose spines, besides with a much shorter one on the outside and a minute seta on the inside. Otherwise as in female.

Occurrence: On *Siganus fuscesens* (HOUTTUYN), at Seto, Wakayama Pref. and at the vicinity of Yamada, Mie Pref. Numerous specimens of both sexes.

Remarks: The new species is characterized, above all things, by the cordiform genital segment of the female, and by the 4th pereiopoda which show an unusual direction of the articulation line between the 2nd and the 3rd segments. Maxillipeds of the female are extraordinarily slender and feeble, whereas they are powerfully developed in the male, The 5th pereiopoda are reduced in the female into 2 setae on either side of the genital segment, and 2 pairs of setae-tipped processes of this segment in the male represent this and succeeding pairs of limbs. The new species will be recognized by the combination of these characters.

Caligus tesserifer n. sp.

(Fig. 5)

Measurements in mm.

	Body	Carapace	4th thoracic segment	Genital segment	Abdomen	Length of 1st abd. seg.	Length of 2nd abd. seg.
Female	7.00	3.36×2.78	0.50×1.07	1.69×1.71	1.57×0.64	1.00	0.57
Male	5.65	3.50×2.93	0.48×1.21	1.00×1.25	0.71×0.86	0.26	0.50

Female (Fig. 5, B, M): Color in alcohol yellowish, without pigment spots.

Carapace ovate, half as long as body, a little longer than wide. Two sides flatly round, with narrow flange. Frontal plate broad, slightly arched anteriorly, with oval lunules at extreme lateral ends. Post-median lobe 3/5 as wide as carapace, with widely round border. Lateral lobes extending beyond spine-like lateral portions of thoracic area, as far as posterior border of median lobe. Posterior sinus deep but narrow. Cross-bar of the H-shaped dorsal groove arched anteriorly. Fourth thoracic segment 2/5 as wide as carapace, twice wider than long, transversely ovate, but contracted in front into a short neck. Genital segment large, about half as long as carapace, slightly narrower than long. It is flask-shaped, having gracefully round antero-lateral angles, almost parallel sides and reentrant posterior margin, so that a short somewhat triangular lobe projects on either side. Abdomen 2-segmented, narrow and elongate, being slightly shorter than foregoing segment. First segment a trifle longer than 2nd which is produced on midline in a bilobed process. Egg string very long and rather thin.

Apical joint of 1st antenna half the length of the basal. Terminal claw of 2nd antenna short, abruptly curved at the tip; basal hook rudimentary and blunt. Maxillary hook undiscovered. Second maxilla undivided, dactyliform, with a minute seta in front of its base. First maxilliped short and small, composed of 2 joints of unequal length, but the 1st rather thick and the 2nd much slender; the latter provided with an acuminate lamina a little behind the tip which carries 2 simple spines. Basal joint of second maxilliped much swollen, with uneven surface; terminal claw strong, having sharp, curved tip and a short seta at about the center. Sternal fork with 2 branches divergent in a V-shape, and with a round accessory tubercle on either side of the base.

Arrangements of spines on the pereiopoda will be clarified by the table on the page 91.

Fig. 5. *Caligus tesserifer* n. sp. A, male, dorsal view; B, female, dorsal view; C–L, male; C, 1st antenna; D, 2nd antenna with maxillae; E, 1st maxilliped; F, sternal fork; G, 2nd maxilliped; L, posterior end of body, ventral view; M, female, 2nd antenna. A, B ×9.3; C–M ×32.

Second joint of 1st pereiopod with a short spur at outer distal angle and fine cilia along inner border; 3rd joint tipped by 3 ciliated spines as well as an inner seta. External spine of 1st joint of exopodite of 2nd pereiopod with

Pereiopod	Border	Protopodite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer			3p, 1s				
	Inner		c	3P				
II	Outer		1H	1H	2h	c	c	c
	Inner	1P	1P	1P	6P	1P	2P	6P
III	Outer	f	1H	1h, c	3h		c	
	Inner	1P, f	1P	1P	4P	1P	6P	
IV	Outer		1P	1P	1P, 2H			
	Inner				1rh			

a narrow lunular flap on either edge. Protopodite of 3rd pereiopod with marginal flanges and with 2 rami far apart from each other. Basal hook of exopodite not crooked as in usual but in the form of a straight spine, with a narrow wing on each border, giving it a spatulate appearance. Fourth pereiopod well developed, 4-jointed; 1st joint rather thick, as long as the rest joints combined, but much wider in calibre; these latter each carries a plumose spine at outer distal angle, the 4th alone bearing, in addition, 2 simple longer spines and ending in a minute spur at inner angle. Fifth pereiopod wanting. Caudal ramus very short, tipped by 3 plumose spines and a minute simple one of the outside.

Male (Fig. 5, A, C–L): Without pigment.

Carapace about 3/5 as long as body, with an outline resembling that of female, but somewhat wider. Post-median lobe extending a little beyond lateral lobes, with margin slightly sinuate in the middle. Fourth thoracic segment as in female, but a little wider. Genital segment much shorter than in this sex, 2/7 as long as carapace, a little broader than long, nearly squarish, having flatly round sides. Abdomen wider and much shorter than in female, 2/3 as long as genital segment, 2-segmented; anterior segment shorter than the posterior which has a bilobed median projection.

Terminal claw of 2nd antenna bears a sharp accessory spine at the center of inner margin and a broader but lower process close to the base; basal spine sharper than in female. Rudiment of 5th pereiopod represented by a round lobe tipped by a few setae at either post-lateral angle of genital segment. Otherwise as in female.

Occurrence: On *Katsuonus vagans* (LESSON), at unknown locality of Izu Peninsula, collected by K. OOYAMA. 8 females and a male.

Remarks: The new species closely resembles *belones* WILSON and *latifrons* WILSON in the configuration of the posterior segments of the female, but the

dissimilarities in the structure of the appendages are very large. The present species is characterized, above all things, by that the apical spines of the 1st pereiopoda and those on the inner distal angles of the terminal 3 joints of the 4th pereiopoda are all ciliated, and by that the basal hook on the exopodite of the 3rd pereiopoda is flanged by narrow laminae exhibiting the appearance of an arrow-head. In the latter point, *tesscrifer* is in accord with *aliuncus* WILSON, but differ in the absence of elongate whip-like appendage which is present on the 1st joint of the 4th pereiopod of WILSON's species and in the abdomen being composed of 2 segments instead of 4.

Caligus cordiventris n. sp.

(Fig. 6)

Female (Fig. 6): 1.96 mm long, carapace 1.23 mm × 1.17 mm, post-median lobe 0.61 mm wide, genital segment 0.61 mm × 0.69 mm, abdomen 0.15 mm × 0.19 mm, egg string 1.40 mm long. Color in alcohol yellowish, sparsely dotted with granular or dendritic pigment spots on dorsal surface.

Carapace a trifle longer than wide, 5/8 as long as body, broader posteriorly than anteriorly. Frontal plate prominent, less than 2/3 as wide as carapace, nearly straight on margin and with oval lunules at extreme lateral ends. Lateral margin of carapace nearly straight or very slightly depressed in the middle, well round only at 2 ends and bordered with well-developed flange. Post-median lobe half as wide as carapace, extending beyond lateral lobes and with widely round margin. Posterior sinus small, oval, parallel to central axis. Cross-bar of the H-shaped dorsal groove arched anteriorly and anterior arms of the vertical grooves very short. Fourth thoracic segment completely coalesced with the genital not to remain any trace of articulation. The composite segment wider than long, half time as long as carapace, flask-shaped. It contracts in front into a narrow neck showing a gracefully round antero-lateral angle; 2 sides slightly depressed and posterior border with a low but broad bulge at the center, but sinuous between this and each post-lateral corner which is well round. Abdomen small, 1-segmented, a little wider than long, 1/3 as long as genital segment, with posterior border wedge-shaped, caudal rami attaching to the sides of the wedge.

First antenna has apical joint thin and much shorter than the basal. Second antenna proportionately small, with terminal claw feeble, abruptly curved only at the tip, and reinforced by a blunt basal spine posteriorly.

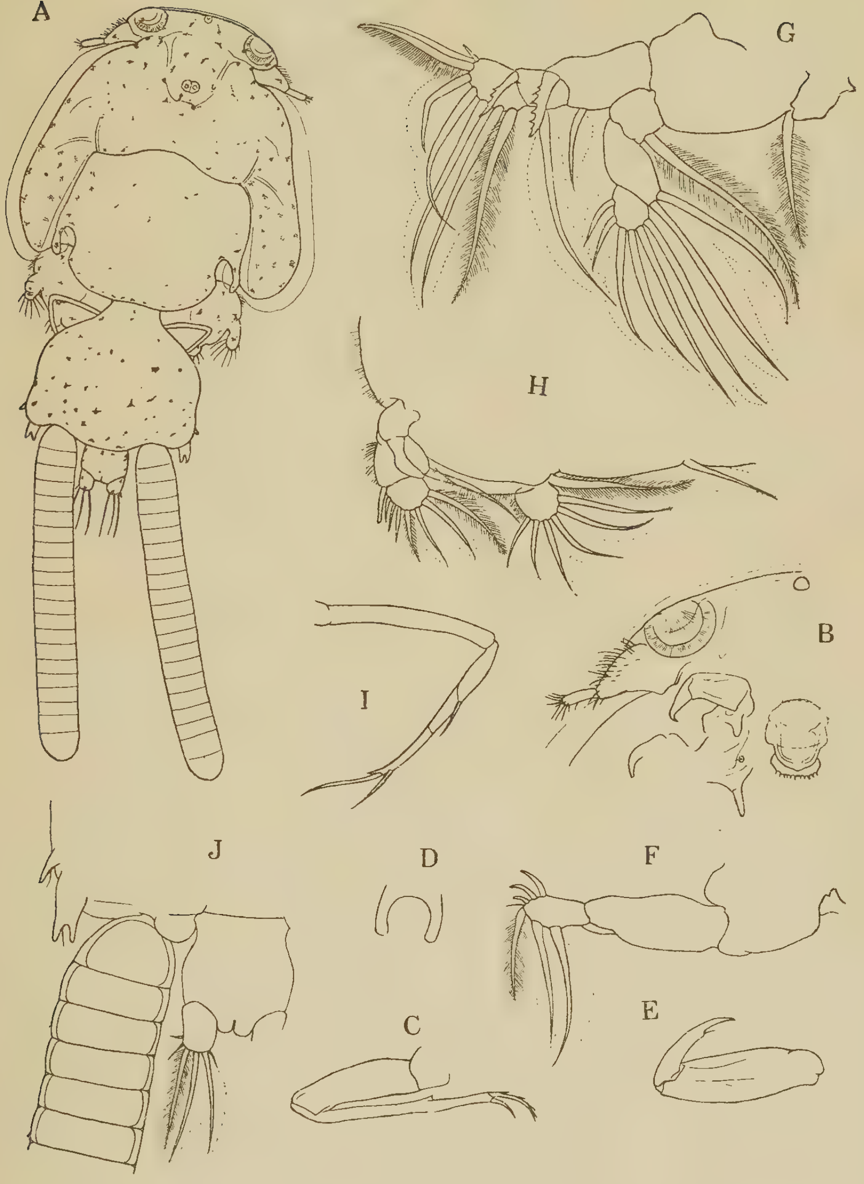

Fig. 6. *Caligus cordiventris* n. sp., female. A, dorsal view; B, cephalic region, ventral view; C, 1st maxilliped; D, sternal fork; E, 2nd maxilliped; F, 1st pereiopod; G, 2nd pereiopod; H, 3rd pereiopod; I, 4th pereiopod; J, post-lateral part of genital segment with abdomen. A ×32; B, J ×72; C–I. ×118.

Maxillary hook sharp, well curved; 2nd maxilla undivided, straight and dactyliform, with a minute spinule in front of the base. Terminal joint of 1st

maxilliped slender, rather straight, a half time longer than the basal and furnished with a minute acuminate lamina on inner border about 1/3 the distance from the tip; inner member of 2 terminal spines longer than the other, fringed with a few cirri on its edge. Second maxilliped comparatively feeble, having basal joint dilated not very much, 3.5 times as long as wide; apical joint half as long as the basal, insensibly curved and with a spinule a short distance from its acuminate tip. Sternal fork a broad U-shape, interposing a wide circular sinus between 2 branches which are blunt and slightly curved in towards each other.

Arrangements of spines on the pereiopoda are tabulated as in the following:

Pereiopod	Border	Protopodite	Exopodite 1st joint	Exopodite 2nd joint	Exopodite 3rd joint	Endopodite 1st joint	Endopodite 2nd joint	Endopodite 3rd joint
I	Outer				3H, 1s			
	Inner				3P			
II	Outer		1H	1H	1h			
	Inner	1P	1P	1P	6P	1P	2P	6P
III	Outer	c	1H	c, 1H	3H	c	c	
	Inner			1P	4P	1P	6P	
IV	Outer		1H		2H			
	Inner				1h			

Third joint of 1st pereiopod with 3 curved, short, apical claws and a thin seta besides 3 longer plumose spines. In 2nd pereiopod, first 2 joints of exopodite with a spine having serrated external edge at their outer distal angles; outermost of the 6 terminal spines on 3rd joint is unlike others being ciliated only on inner edge, while with a narrow flap on the outer. Basal hook on exopodite of 3rd pereiopod slightly swollen about the center of distal joint, blunt at the tip and scarcely curving inwards. Fourth pereiopod long, slender, 4-jointed; 1st joint as long as remaining joints put together, 2nd with a terminal spine, 3rd lacking, and 4th with 2 long external spines besides a short internal spur. Fifth and 6th pereiopoda represented respectively by a simple spine like process and a bifurcate columnar one arranged in front and behind at either post-lateral corner of genital segment. They are provided each with a short seta and visible from dorsal side. Caudal ramus short, armed with 3 ordinary plumose spines besides 3 simple short setae, arranged one on inside and 2 on outside.

Male unrepresented in the present collection.

Occurrence: 5 females on *Xesurus scalprum* (CUVIER & VALENCIENNES) at Seto, Wakayama Pref.

Remarks: The present species is recognized by that the exopodite of the 2nd pereiopod has a serrated spine on the outer distal angle of each of the first 2 joints and by the very slender 4th pereiopod. Inner member of the apical spines of the 2nd maxilla is ciliated, and the last 2 pairs of pereiopoda are represented by 2 processes on each post-lateral angle of the genital segment, one being simple and spine-like, while the other bifid at the tip. These also may be regarded as other characteristics of this species.

Genus Lepeophtheirus Nordmann 1832

Lepeophtheirus goniistii Yamaguti 1936

(Figs. 7-9)

YAMAGUTI, S., 1936. Parasitic Copepods from Fishes of Japan, Pt. 2, Caligoida I, pp. 10-12, Pl. VIII, figs. 114-131, Pl. IX, figs. 132-133.

This species was precisely studied by Yamaguti. As my specimens are in complete agreement with his, I remain to give here only a brief account as regards the principal points of characters. Younger females, however, are to be described for the first time.

Measurements in mm:

	Body	Carapace	4th thoracic segment	Genital segment	Abdomen
Female	3.97	2.70×2.56	1.48×1.00	0.78×1.22	2.22×2.22
Male	2.74	1.94×1.84	0.16×0.58	0.42×0.42	0.16×0.23

Female (Figs. 7, B & 8, A-K): Color in alcohol yellowish, spotted with dendritic pigment on both surfaces.

Carapace orbicular, wider posteriorly than anteriorly. Post-median lobe slightly extending beyond lateral lobes, with widely round margin and more or less angular at lateral corners. Posterior sinus shallow and wide. Fourth thoracic segment transversely linear. Genital segment has evenly round sides and slightly reentrant hind margin, except for a small triangular projection on either side of midline. Abdomen small, squarish, non-articulated. Egg string shorter than carapace.

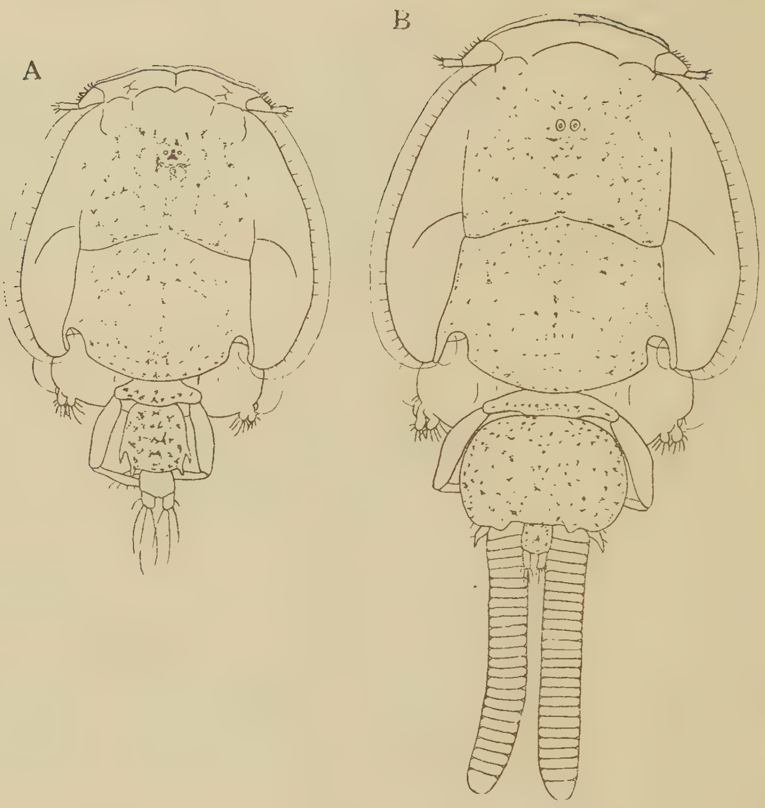

Fig. 7. *Lepeophtheirus goniistii* Yamaguti. A, male, dorsal view ×21; B, female, dorsal view ×18.

Second antenna has terminal hook slender and undivided at its tip; basal spine blunt. Maxillary hook small; second maxilla bifurcate. Distal joint of 1st maxilliped furnished with a dactyliform lamina at about the middle of its length, and 2 unequal setae at the apex. Teminal claw of 2nd maxilliped small, shorter than half the length of basal joint, only slightly curved, and with a short seta on inner margin. Sternal fork divergent.

Arrangements of the spines on the pereiopoda are shown in the table on the next page.

First pereiopod has a fleshy spine on protopodite; 3rd joint bears 5 terminal claws, of which the inner 2 are much smaller than others. Exopodite of 2nd pereiopod possesses an acuminate lobe on outer distal angle of 1st joint and endopodite is ciliated on the outer margin of 2nd. Third pereiopod has basal hook of exopodite forked into 2 unequal branches. Basal joint of 4th

Pereio-pod	Border	Protopodite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer		1s	3H, 2h				
	Inner	1H		3P				
II	Outer	1s	1H, f	1H	1H, 1p		c	
	Inner	1P, c	1P	1P	6P	1P	2P	6P
III	Outer	f, 1s	1H	1h	3h			
	Inner	f, 1p	1P	1P	4P	1P	6P	
IV	Outer	1rh	1H	3H				
	Inner							

pereiopod robust, as long as the rest joints combined together; 2nd joint tipped by a very minute spine. Fifth pereiopod is represented by a narrow triangular lobe, projecting from post-lateral angle of genital segment and furnished with a few setae. Caudal ramus with 3 longer plumose spines and a far shorter simple one on each side of them.

Male (Figs. 7, A, & 8, L–O): Slightly smaller than female.

Carapace resembles that of this sex, but genital segment is proportionally smaller. The latter nearly quadrangular and provided with 2 pairs of acuminate processes arranged in front and behind at post-lateral angles of segment and tipped each with a few setae. These are indicative of the rudiments of 5th and 6th pereiopoda. Abdomen squarish, about 1/3 as long as genital segment.

Second antenna 3-jointed, with file-like surface due to the development of parallel striations; terminal joint divided into 2, more or less curved, divergent claws and a smaller one situated between but somewhat below them. Maxillary hook stronger than in female. Basal joint of 2nd maxilliped armed with 2 rectangular tubercles near distal end of its inner margin. Basal hook on exopodite of 3rd pereiopod simple. Caudal ramus relatively broader than in female, terminating in 3 plumose spines and 3 simple, much shorter setae, one on inside and 2 on outside of them. Otherwise as in female.

Younger females: Besides the mature specimens the present collection includes two more sorts of individuals, which are smaller in the body size and different in the constitution of genital segment. They appear to represent the developmental stages of the females.

a) Juvenile form 1 (Fig. 9, D): Genital segment proportionally smaller than in adult and not much inflated though resembling in shape; 1/7 as long as body, narrower than 4th thoracic segment. Fifth pereiopod relatively larger and exposed nearly entirely in dorsal view.

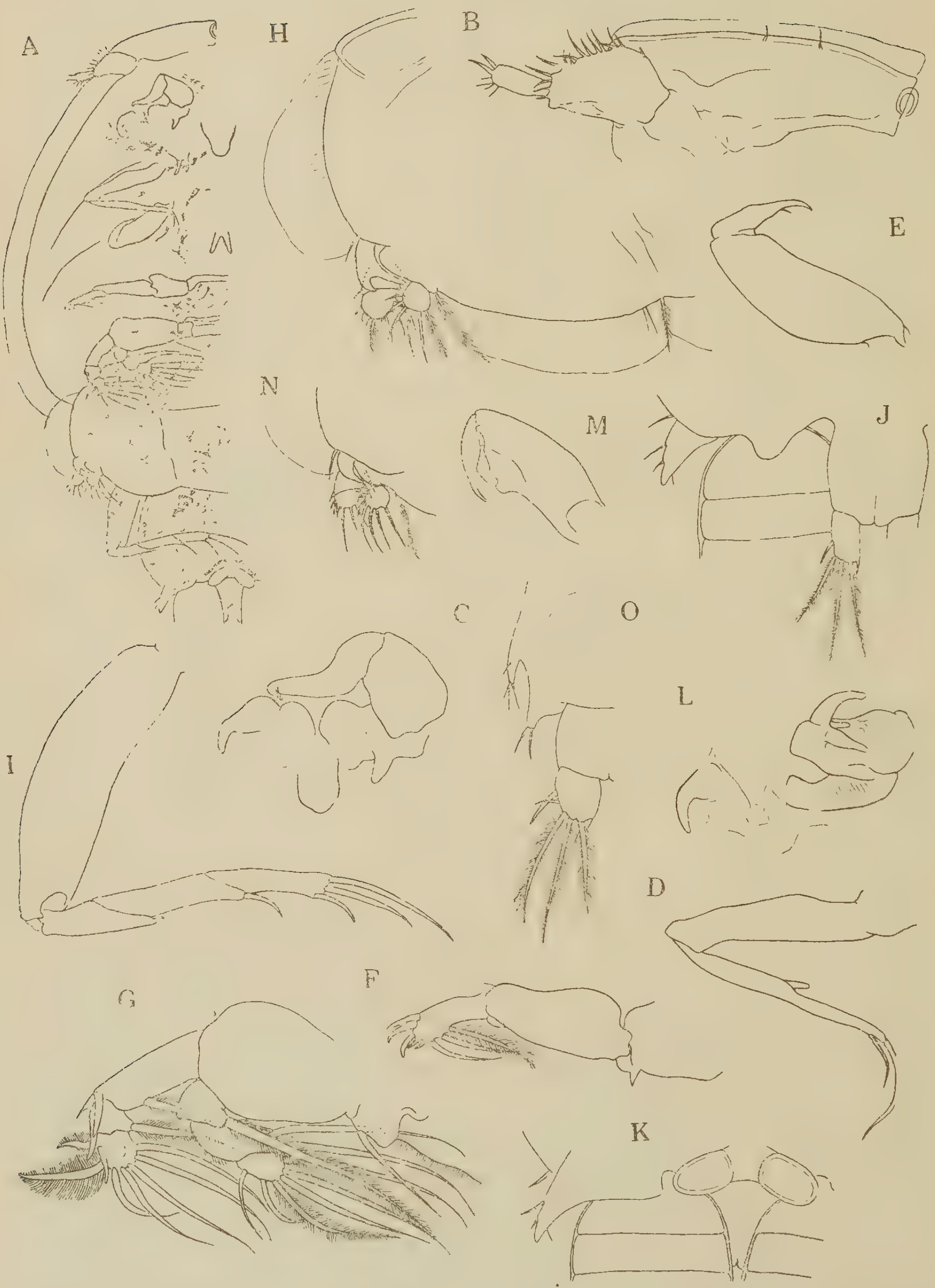

Fig. 8. *Lepeophtheirus goniistii* Yamaguti. A–K, female; A, ventral view of right half of body; B, 1st antenna; C, 2nd antenna with maxillary hook; D, 1st maxilliped; E, 2nd maxilliped; F, 1st pereiopod; G, 2nd pereiopod; H, 3rd pereiopod; I, 4th pereiopod; J, post-lateral part of genital segment with abdomen, dorsal view; K, same, ventral view; L–O, male; L, 2nd antenna with maxillary hook; M, 2nd maxilliped; N, 3rd pereiopod; O, genital segment with abdomen, left half, dorsal view. A ×21; B–O ×59.

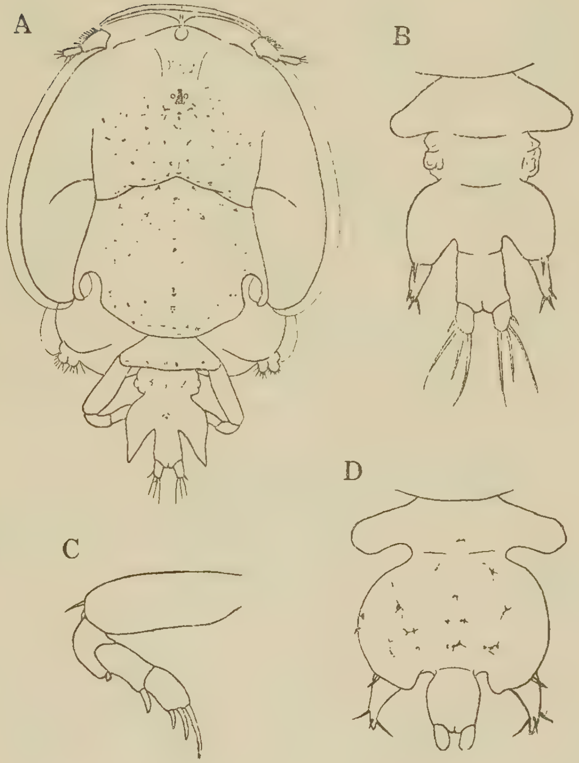

Fig. 9. *Lepeophtheirus goniistii* Yamaguti. A–C, youngest stage; A, dorsal view; B, posterior part of body, dorsal view, C, 4th pereiopod; D, somewhat older stage, posterior part of body, dorsal view. A ×21; B ×37; C ×59; D ×32.

b) Juvenile form 2 (Fig. 9, A–C): Fourth thoracic segment trapezoid, rapidly narrowing towards the front, 1/3 as wide as carapace. Genital segment 1/8 the length of entire body on the midline, divided into 2 parts by a pair of deep lateral notches. Anterior portion more or less wrinkled on the sides; posterior portion somewhat wider, and prolonged backwards on either side into a triangularly acuminate lobe. Fourth pereiopod more stumpy than in adult, but with full number of spines.

From the reasons that the terminal hook of the 2nd antenna is simple, that the exopodite of the 3rd pereiopod has a bifid basal hook and that the case in which this type of individual was clasped by the male, reminding one a copulation, was observed, I am lead to believe this to represent a young stage of the female.

Measurements of juvenile forms in mm.

	Body length	Carapace	4th thoracic segment	Genital segment	Abdomen
Juvenile form 1	3.00	2.07×2.00	0.19×0.78	0.45×0.67	0.17×0.17
Juvenile form 2	1.67	1.18×1.09	0.12×0.35	0.33×0.29	0.13×0.10

Occurrence: Very common. On *Goniistius zonatus* (CUVIER & VALENC.) at Seto, Wakayama Pref., at Tôsi Is., Mie Pref., at Nagaturo, Sizuoka Pref.; on *Siganus fuscescens* (HOUTTUYN) at Seto, at Tôsi Is., off Yamada, Mie Pref.; *Pseudopeneus chrysopleuron* (TEMMINCK & SCHLEGEL) at Nagaturo; on *Callyodon ovifrons* (TEMMINCK & SCHLEGEL) at Seto. Numerous specimens of both sexes.

Remarks: Although YAMAGUTI speaks of this species as to lack any pigment, it has well-developed black spots on the central part of the carapace as well as on other segments on both dorsal and ventral surfaces in both the sexes. His specimens were found on *Goniistius zonatus*. My collection adds to this the 3 hosts listed above.

Lepeophtheirus uenoi Yamaguti 1939

(Figs. 10 & 11)

L. uenoi YAMAGUTI, S., 1939, Vol. Jubilae Prof. S. YOSHIDA, vol. 2, Pl. XVI–XVII.

Measurements in mm.

<table>
<tr><th></th><th>Body length</th><th>Carapace</th><th>4th thoracic segment</th><th>Genital segment</th><th colspan="2">Abdomen</th></tr>
<tr><td>Female</td><td>14.50</td><td>5.20×4.50</td><td></td><td>5.10×4.00</td><td colspan="2">4.00×1.20</td></tr>
<tr><td rowspan="2">Male</td><td rowspan="2">7.14</td><td rowspan="2">4.22×3.78</td><td rowspan="2">0.43×1.00</td><td rowspan="2">1.43×1.29</td><td colspan="2">1.07×0.64</td></tr>
<tr><td>1st segment 0.36×0.14</td><td>2nd segment 0.71×0.14</td></tr>
</table>

Female (Fig. 10): Color in alcohol yellowish, without pigment spots.

Carapace ovate, with evenly round sides, a trifle longer than wide and about 1/3 as long as body. Frontal plate narrow and small, with a median notch. Post-median lobe extending beyond lateral lobes, less than half the entire width, trapezoid on posterior border. Cross-bar of the H-shaped dorsal groove bending slightly forwards. Fourth thoracic segment very small, less than 1/3 the width of carapace, narrowing both in front and behind to form

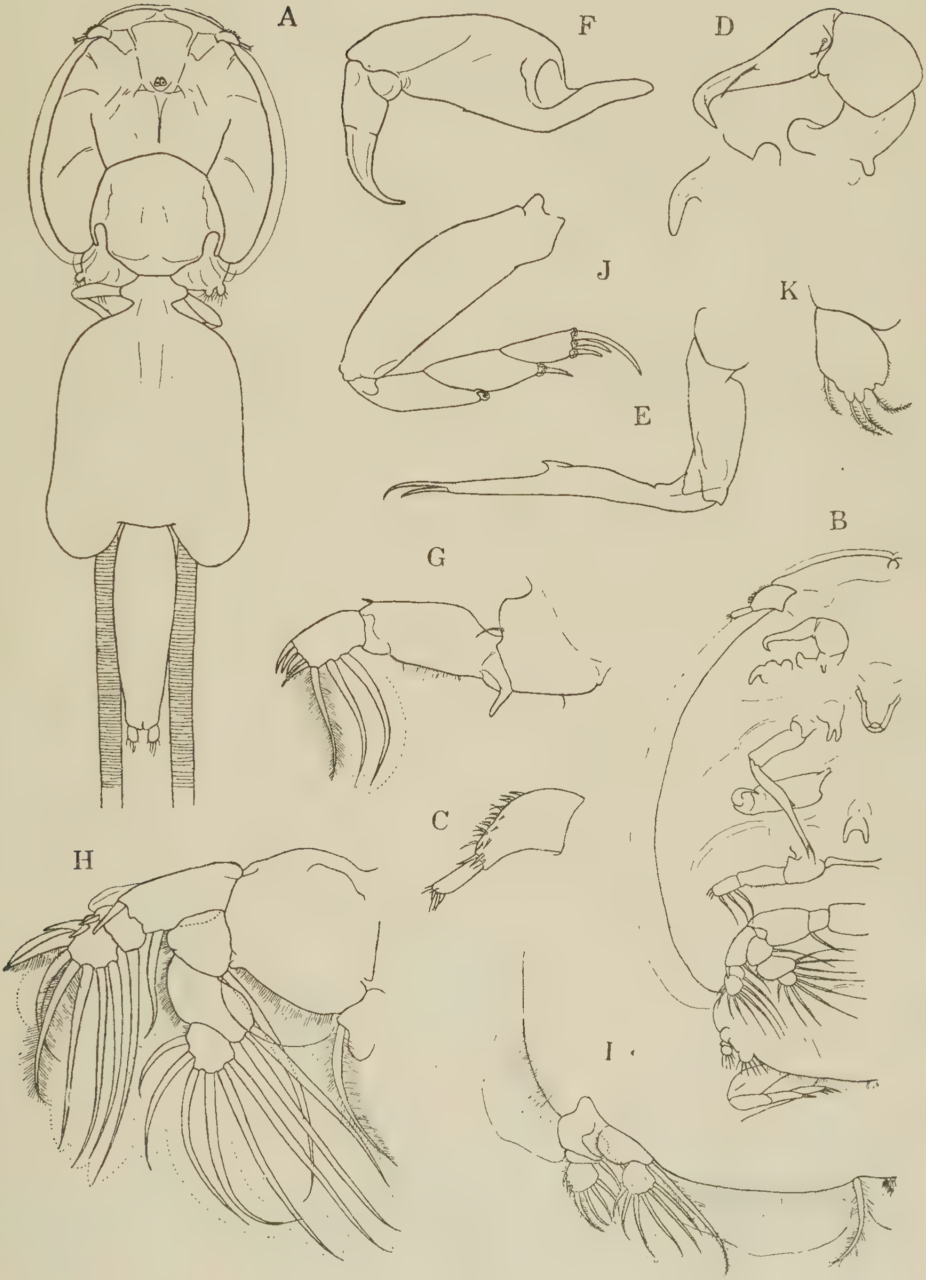

Fig. 10. *Lepeophtheirus uenoi* Yamaguti, female. A, dorsal view; B, right half of carapace, ventral view; C, 1st antenna; D, 2nd antenna with maxillary hook; E, 1st maxilliped; F, 2nd maxilliped; G, 1st pereiopod; H, 2nd pereiopod; I, 3rd pereiopod; J, 4th pereiopod; K, caudal ramus. A ×6.7; B ×12; C–K ×32.

a short neck. Genital segment large and swollen, nearly as long as and 1/5 narrower than carapace. It is evenly curved at antero-lateral corners, almost parallel on the sides and produced back in a pair of large, well-round lateral lobes. Demarcation between this and the following segment indicated merely by deep lateral notches. Abdomen unsegmented and elongate to form a cylindrical segment which is as long as the genital. It is widest on the level 1/5 of its own length, slightly tapering both forwards and backwards, and has 1 or 2 inconspicuous constrictions near the posterior end. Egg string 3 times as long as body.

Distal joint of 1st antenna shorter than the basal. Terminal claw of 2nd antenna abruptly curved at the apex; basal process minute and dactyliform. Maxillary hook with blunt tip; 2nd maxilla with bifid ends slightly curving outwards. Distal joint of 1st maxilliped twice as long as the proximal, and furnished with a triangular lamina about the middle. Second maxilliped has 1st joint swollen and the 2nd sharp, well curved like a hook. Sternal fork a U-shape, both rami of the U being somewhat divergent and obtuse at their ends.

Arrangements of the spines on the pereiopoda are:

Pereiopod	Border	Protopodite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer	1s	1rh	3H, 1p				
	Inner	1s, 1H	c	3P				
II	Outer		1H, f	1H	2H	c	c	c
	Inner	1P, f	1P	1P	6P	1P	2P	6P
III	Outer	f	1H	c	3h, c	c		
	Inner	1P, f	1P	1P	4P	1P	6P	
IV	Outer		1 h	1H	3H			
	Inner							

First pereiopod stumpy, and with a fleshy spine in the articulation part between first 2 joints; apical spines on the hand consist of 3 simple and a plumose ones. Exopodite of 2nd pereiopod bears a small lamellar flange on outer margin of 1st joint; outermost of the 6 apical spines of this ramus rimmed along outer edge by a narrow lamina instead of cilia. Basal hook on exopodite of 3rd pereiopod bent inwards at a right angle. Fourth pereiopod stout; 1st joint slightly longer than the rest 3 combined, 2nd with a minute curved claw at outer distal angle, 3rd with a spine, and 4th with 3, innermost of which is much longer than others; all spines with a short semicircular fringed lamina at their bases. Fifth pereiopod missing. Caudal ramus small,

furnished with 4 short plumose setae, of which the inner 3 project each from summit of a small papilla; inner margin of the ramus ciliated.

Male (Fig. 11): Color yellowish, without pigment spots.

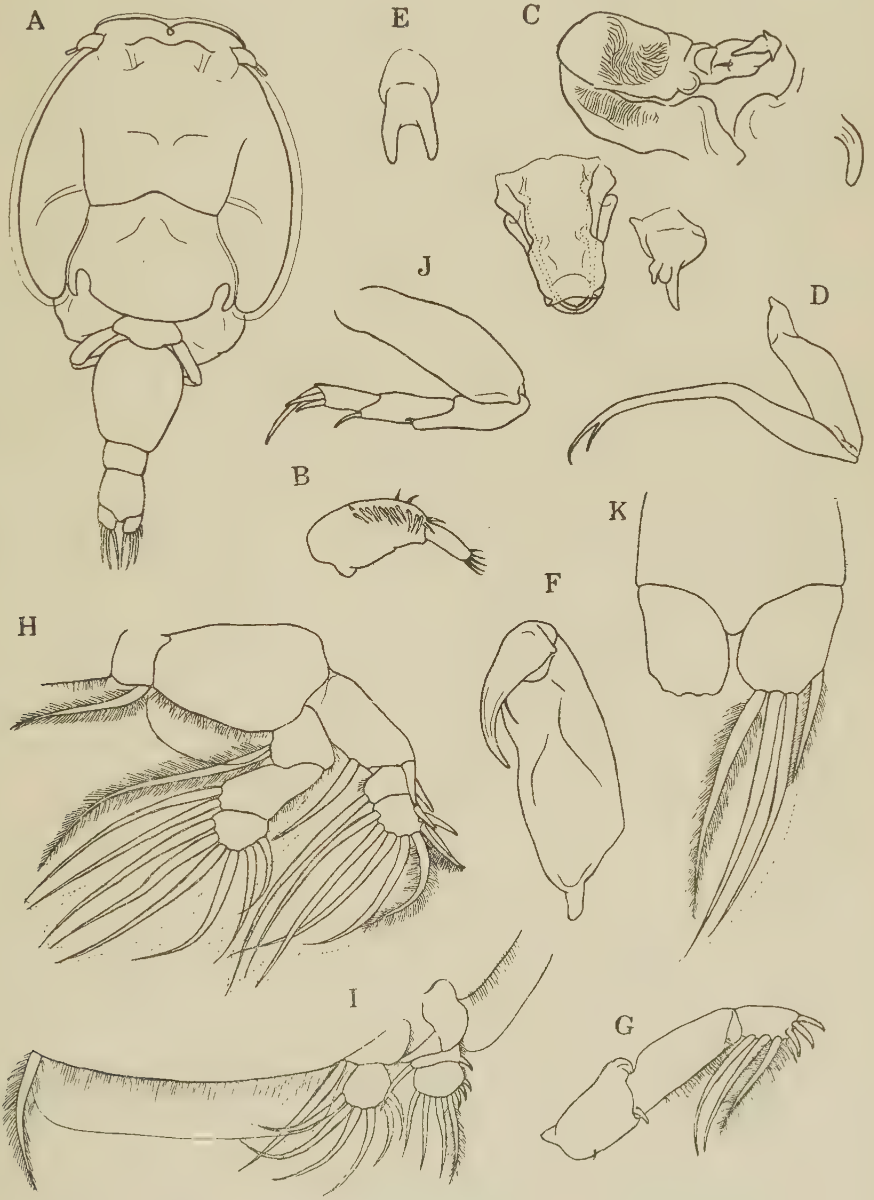

Fig. 11. *Lepeophtheirus uenoi* Yamaguti, male. A, dorsal view; B, 1st antenna; C, 2nd antenna, maxillae and oral tube; D, 1st maxilliped; E, sternal fork; F, 2nd maxilliped; G, 1st pereiopod; H, 2nd pereiopod; I, 3rd pereiopod; J, 4th pereiopod; K, caudal rami. A ×9.3; B–H, J–K ×37; I ×42.

Carapace the same shape as in female, but with frontal plate somewhat more prominent and more conspicuously notched on the median. Post-median lobe with margin round, but more or less angular at lateral corners and only slightly extending beyond lateral lobes. Fourth thoracic segment small, a quarter as wide as carapace, nearly trapezoid, with distinct posterior border. Genital segment about a third of carapace both in length and in width. It resembles a barrel in shape, having well round sides, and widest at about the anterior third of its length. Abdomen 2-segmented, narrower and somewhat shorter than genital segment; 1st segment half as long as the 2nd, which is posteriorly produced at the center.

Second antenna stouter than in female, 3-jointed; basal 2 joints with rasp-like surface owing to the presence of fine striations; 2nd joint furnished with a round discoidal process at distal end. Terminal claw strongly curved, with its apex pointing backwards, and accompanying 2 minute accessory spines, one on each side, besides a shorter seta near the base. Second maxilla forked into 3 spines crowded together; inner 2 short and tuberculiform, while the outer elongate. Distal joint of 1st maxilliped slender, twice as long as the proximal, somewhat crooked at about the center.

Arrangements of spines on the pereiopoda are a little different from those in female as shown in the following table;

Pereiopod	Border	Protopodite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer			3H, 1h				
	Inner	1s, 1H	c	3P				
II	Outer		1H	1H	2H	c	c	
	Inner	1P, f	1P	1P, c	6P	1P	2P	6P
III	Outer	f	1H	1h, c	3h, c	c	c	
	Inner	1P, f		1P	4P	1P	6P	
IV	Outer		1rh	1P	3P			
	Inner							

Fifth pereiopod undiscovered as in female. Caudal ramus broad and short, furnished with 3 longer and a shorter plumose spines, these being far longer and stronger than in other sex.

Occurrence: Unknown locality from Kurile Is., on *Onchorhynchus keta* collected by K. KURONUMA. 2 females and a male.

Remarks: The present females are in strict accord with that described by Yamaguti (1939). In his type, the abdomen appears to be segmented, but

as stated elsewhere, absence of the segmentation in my specimens may have resulted from the preservation in alcohol.

As suggested by that author, this species stands very close to *salmonis* Krφyer from the Atlantic Ocean. The points of differences between the two enumerated by him are: The second joint of the 4th pereiopod has an apex covered by papillae in *salmonis*, whereas it is tipped by a minute curved spine accompanying a small semicircular flange in *uenoi*, and the basal spine of the 2nd antenna absent from the former is present in the latter. Besides these, I must add that the terminal joint of the exopodite of the 2nd pereiopod bears a simple short spine outside the group of much longer plumose spines in the Atlantic species, while 2 of such are discovered in the Pacific one.

White (1940) has stated as regards the females of *salmonis* from the bay of Fundy, from the gulf of St. Laurence, and from the coast of Nova Scotia that the 2nd joint of the 1st pereiopod is quite different from that of the other specimens from the Atlantic in terminating in a short, curved spine and a flange. His figure (cf. Fig. 2, 1940) about this limb clearly indicates this condition and is in complete agreement with that of mine inserted here. He further (1942) reported the male form from those localities, saying that it is also different from this sex of other Atlantic *salmonis*. It is very suggestive that, according to his description and photograph of his male, this too closely resembles the same sex of *uenoi*. I am doubtful, therefore, if White's specimens may really deserve to receive the name of *salmonis*. There is much of the probability that they might be *uenoi*.

Lepeophtheirus parvulus n. sp.

(Fig. 12)

Female (Fig. 12): 4.15 mm long, carapace 2.48 mm × 2.33 mm, 4th thoracic segment 0.30 mm × 0.64 mm, genital segment 1.40 mm × 1.04 mm, abdomen 0.32 mm × 0.28 mm. Color in alcohol yellowish, without pigment spots.

Carapace round, wider posteriorly than anteriorly, with length 3/5 that of body and nearly equal to its own width. Lateral flange rather broad. Frontal plate moderate in size and with a shallow median incision. Transverse bar of the H-shaped dorsal groove slightly sinuate towards the front and anterior half of the longitudinal groove rather short. Post-median lobe about half as wide as carapace, with margin widely round and extending a little beyond lateral lobes. Posterior sinus deep and widely open towards the back. Fourth thoracic segment small, about a quarter the width of carapace,

twice as wide as long and constricted both in front and behind as narrow short neck. Genital segment as long as wide and 2/5 as long as carapace. It has gracefully round antero-lateral angles, parallel sides and reentrant posterior margin, post-lateral corners being somewhat angularly round. Abdomen small, less than 1/3 as long as foregoing segment, non-articulated, quadrangular, with posterior border arched. Egg string occupying 2/5 the body length.

Apical joint of 1st antenna much shorter than the basal and tipped with a few setae. Terminal hook of 2nd antenna slender, curving in an S-form; basal spine blunt, short and dactyliform. Maxillary hook also short and blunt, curved not much; 2nd maxilla with bifid end, turned somewhat outwards. Distal joint of 1st maxilliped slender, a trifle longer than the proximal and furnished with a short seta at the middle of its inner margin, besides being tipped by 2 unequal, curved terminal spines. Second maxilliped has basal joint moderately thick; terminal hook attaining the half of basal, sharply narrowed and curved at the apex. Sternal fork blunt at the tip.

Arrangements of spines on the pereiopoda are tabulated below:

Pereiopod	Border	Protopodite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer Inner	 1H, 1s	1s	4H 3P				
II	Outer Inner	 f	1H 1P	1H 1P	2H 6P	c 1P	c 2P	 6P
III	Outer Inner	f f, 1P	1H 1P	c 1P	c, 3h 4P	 1P	c 6P	
IV	Outer Inner		1rh	1H	3H			

Basal joint of 1st pereiopod has a minute cirrus about the center of its posterior margin and a fleshy dactyliform process at distal end; apical claws of 3rd joint consist of longer outer 2 and somewhat shorter inner 2. Protopodite of 2nd pereiopod with a flange on posterior margin; first 2 joints of endopodite thickly ciliated on their outer margin. Marginal flanges on protopodite of 3rd pereiopod rather broad; basal hook of exopodite as usual in structure, bent at a right angle. Fourth pereiopod slender, with 1st joint slightly shorter than distal 3 combined together; 2nd joint with a rudimentary spine, 3rd with a short one, and 4th with 3 spines of different lengths. Rudiment of 5th pereiopod is a small lobe projecting a little beyond posterior border of genital segment and having obliquely truncate end, where it carries

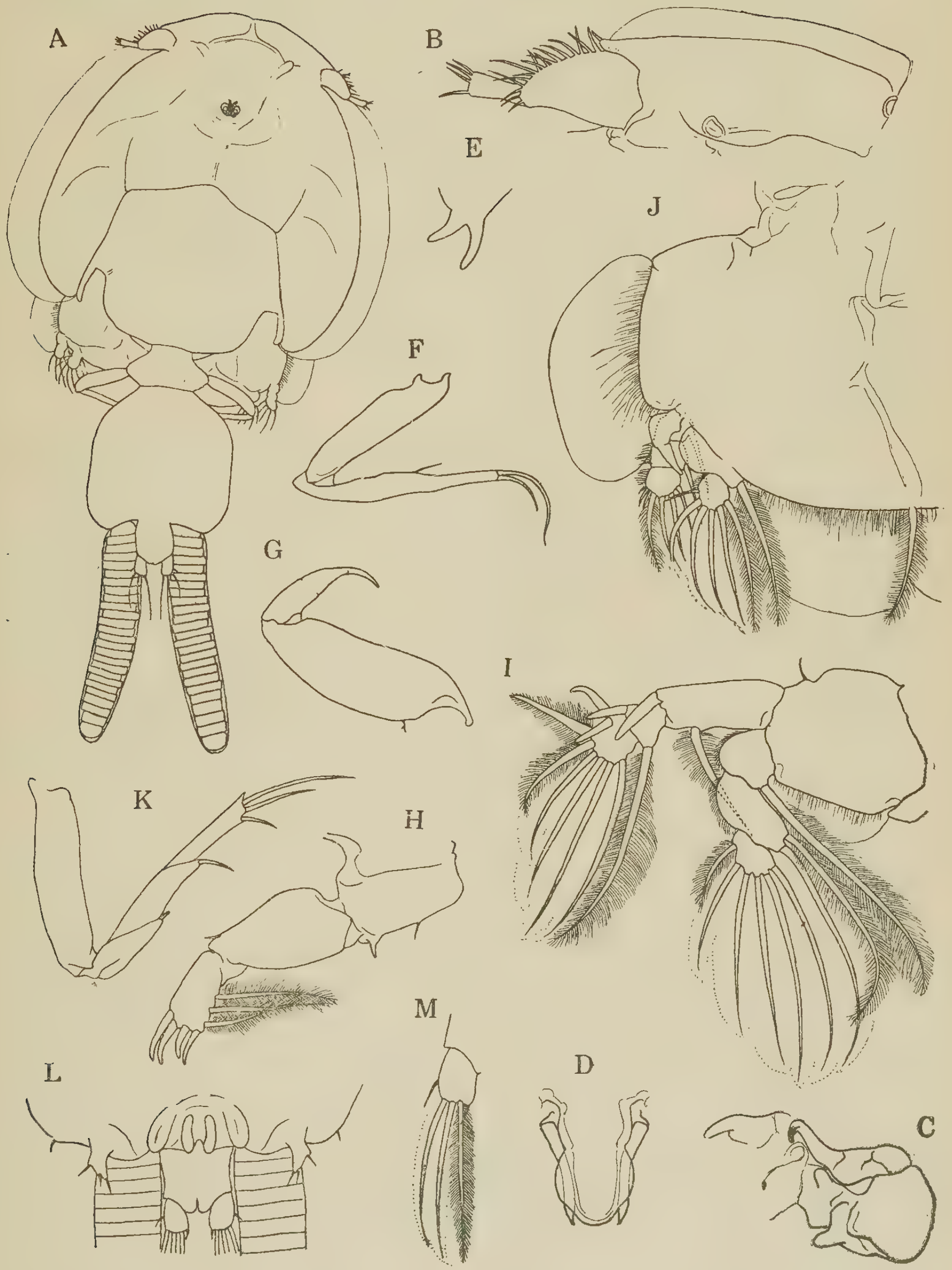

Fig. 12. *Lepeophtheirus parvulus* n. sp., female. A, dorsal view; B 1st antenna, C, 2nd antenna with maxillary hook; D, oral tube; E, 1st maxilla; F, 2nd maxilla; G, maxilliped H, 1st pereiopod; I, 2nd pereiopod; J, 3rd pereiopod; K, 4th pereiopod; L, posterior part of body, ventral view; M, caudal ramus. A ×18; B–K, M ×58; L ×32.

3 short setae. Caudal ramus short and small, with 3 long plumose spines and a minute simple seta on each side of them.

Male unrepresented in the collection.

Occurrence: 3 females on *Sebasticus marmoratus* (Cuvier & Valenc.) at Seto, Wakayama Pref.; 1 female at Nagaturo, Sizuoka Pref. on the same host.

Remarks: In the configuration of the carapace and of the genital segment, as well as in the proportion of the various parts to the entire body, the new species is closer to *bifurcatus* Wilson, *parvus* Wilson, *longispinosus* Wilson, and *semicossyphi* Yamaguti than to others. Above many points of differences, it may be differentiated from these known species by the characters compared in the following table.

	parvulus	*parvus*	*bifurcatus*	*longispinosus*	*semicossyphi*
1st joint of maxilliped	simple	with blunt process	simple	with conical process	simple
sternal fork	blunt	pointed	2 branches bifid	2 branches bifid	with flange
4th pereiopod	normal, 4 jointed	normal, 4 jointed	stumpy, 4-jointed	stumpy, 3-jointed	stumpy, 2-jointed
5th pereiopod	present	absent	absent	absent	present

Lepeophtheirus scutiger n. sp.

(Figs. 13 & 14)

Female (Figs. 13 & 14): 3.45 mm long, carapace 2.03 mm×1.96 mm, 4th thoracic segment 0.31 mm×0.55 mm, genital segment 0.86 mm×1.14 mm, abdomen 0.21 mm×0.28 mm, egg string 1.93 mm long. Color in alcohol yellowish white, with pigment spots on all the segments.

Carapace ovate, wider posteriorly than anteriorly and framed with moderately broad flange. Frontal plate narrow, inconspicuously notched on the midline. Post-median lobe about 2/3 the entire width, slightly extending beyond lateral lobes; posterior margin widely round, but somewhat angular on both sides. Posterior sinus deep and narrow. Cross-bar of the H-shaped dorsal groove bent forwards at the center. Fourth thoracic segment small, wider than long and 1/3 as wide as carapace. It narrows anteriorly into a short neck and continues to succeeding segment without being separated by a distinct line of articulation except by a pair of deep lateral notches. Genital

segment wider than long, a little more than half as wide as carapace, cordiform having well round sides and concave posterior border. Abdomen small, a trifle wider than long, and with a bilobed median process. Egg string almost half as long as body.

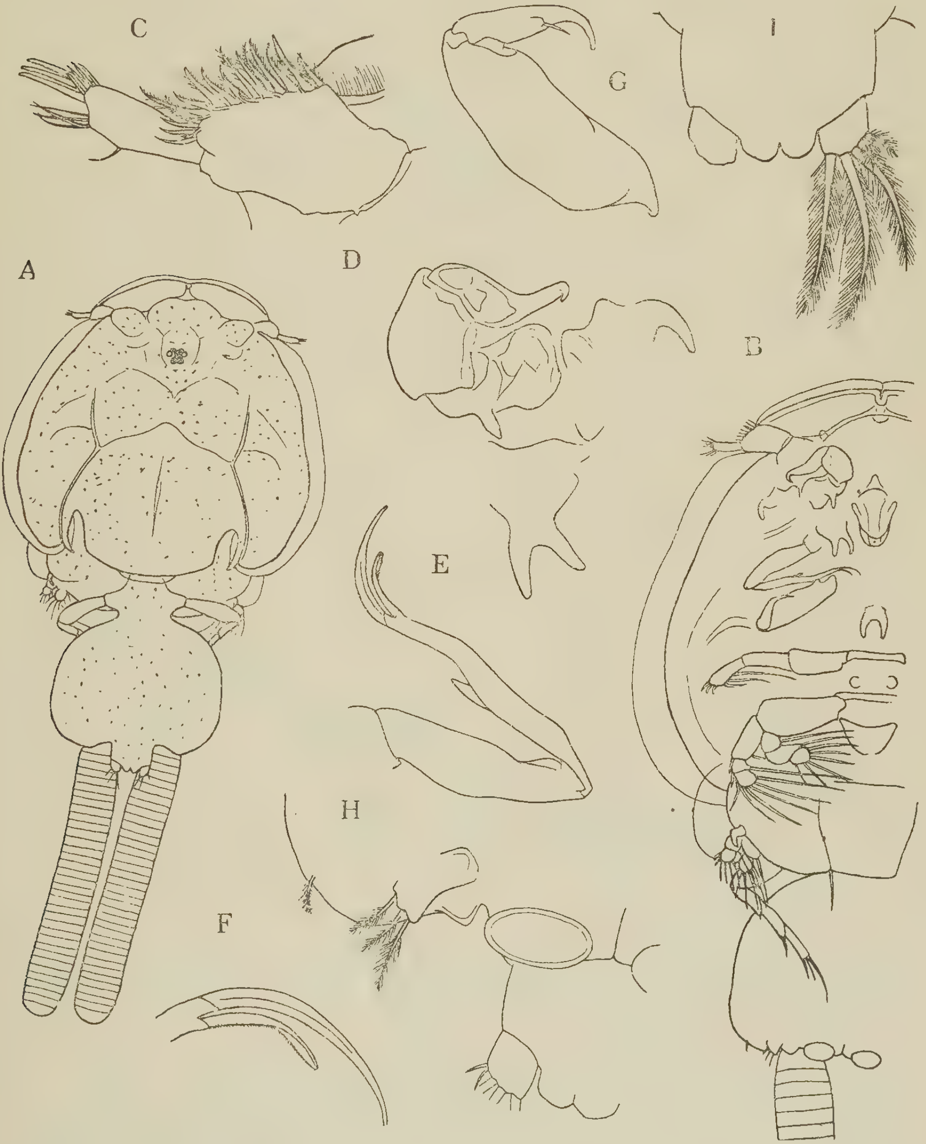

Fig. 13. *Lepeophtheirus scutiger* n. sp., female. A, dorsal view; B, ventral view, right half of body; C, 1st antenna; D, 2nd antenna with maxillae; E, 1st maxilliped; F, tip of same; G, 2nd maxilliped; H, post-lateral part of genital segment with abdomen; I, abdomen with caudal rami. A ×19; B ×28; D–E, G–I ×77; C ×123; F ×174.

Apical joint of 1st antenna shorter than the basal, both being thickly setaceous. Distal joint of 2nd antenna as usual, with simple and hook-like tip; basal spine dactyliform. Maxillary hook strongly curved; 2nd maxilla bifid, having divergent rami. Distal joint of 1st maxilliped slender, more or less crooked and with a triangular lamina on inner border at about the center; shorter member of 2 apical spines with finely serrated edge. Second maxilliped has 1st joint moderately thick and the 2nd sharpened towards the tip, bent abruptly, and provided with a seta at about the middle. Sternal fork a U-shape, with rami slightly curving towards each other.

Arrangements of the spines on the pereiopoda are tabulated as in the following:

Pereiopod	Border	Protopodite	Exopodite			Endopodite		
			1st joint	2nd joint	3rd joint	1st joint	2nd joint	3rd joint
I	Outer		1h	1s, 3H, 1p				
	Inner	1P	c	3P				
II	Outer		1H, f	1H	2H	c	c	
	Inner	1P, f	1P, c	1P, c	6P	1P	2P	6P
III	Outer	f, 1p	1H	c	c, 3h	c	c	
	Inner	f, 1P	1P	1P	4P	1P	c, 6P	
IV	Outer		1rh	1H	3H			
	Inner							

First pereiopod with a blunt, more or less fleshy spine on the articulation part between first 2 segments; most internal of 4 apical claws on 3rd joint the smallest and finely plumose. On mid-ventral surface, between this and following pairs of limb a pair of oval tubercles present. Basal joint of 2nd pereiopod rimmed with a broad flange along posterior border, and 1st joint of exopodite also with a narrow flange on outer margin; of 2 simple spines on 3rd joint of exopodite, distal one is crooked and bears a narrow rim on its outer edge. Flanges and basal joint of 3rd pereiopod rather broad; basal hook of exopodite simple, bent inwards at apical part. First joint of 4th pereiopod rather thick, as long as other 3 put together; 2nd joint tipped by a minute curved spine, 3rd with 1, and 4th with 3 of graded lengths; all of them with a small lunular flange at their bases and, except the smallet one, finely serrated on their borders. Fifth pereiopod a small triangular lobe present close to posterior border of genital segment on either side, and with 3 minute plumose spines on outer border. Caudal rami short, apart from each other by intrusion of posterior process of abdomen between them; they possess 3 plumose spines and 2 similar but much smaller ones on the outside.

Fig. 14. *Lepeophtheirus scutiger* n. sp., female. A, 1st pereiopod; B, 2nd pereiopod; C, 3rd pereiopod; D, same, inner view; E, 4th pereiopod; F, tip of same. A–C, E ×77; D ×123; F ×173.

Occurrence: 5 females on *Hexagrammos otakii* JORDAN & STARKS, at Momotori, Mie Pref.

Remarks: The present species is closest to *parvulus*, but can be discriminated by the characters compared on the next page. The two are also different in the constitution of the 5th pereiopoda, caudal rami, and so on.

		scutiger	*parvulus*
Distal joint of 2nd maxilla		with a lamina about the middle	with a seta about the middle
Distal joint of maxilliped		with a spine	without spine
1st pereiopod	Inner border of 2nd joint	ciliated	non-ciliated
	Innermost claw of 3rd joint	plumose	simple
Outer border of 1st joint of exopodite of 2nd pereiopod		with a flange	without flange
Spines of 4th pereiopod		with a basal rim	without basal rim

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FOUR NEW COPEPODS FROM SUBTERRANEAN WATERS OF JAPAN

(*With* 25 *text-figures*)

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Our knowledge of the subterranean copepods of Japan is far from complete, having been reported previously only by the works of UÉNO (1934a, Japan. Proc. Imp. Academy, X, 229–232. 1934b, Annot. Zool. Japon., 14, 449–450). He reported a new species, *Eucyclops nagasakai* from a subterranean pool in a cave at Hirogawara in Prov. of Shinano, central Japan and also from a well at the town of Pi-tzu-wo in Kwantung Prov., southern Manchuria.

Recently, Messrs YOSHIFUMI MIURA and YOSHINOBU MORIMOTO cellected very interesting crustaceans belonging to Bathynellidae (Syncarida), from wells in the water-works of both Himeji and Aioi cities, western Japan. Copepods associated with those bathynellids were placed at my disposal for study.

Besides these, a few years ago, I found three species of subterranean copepods from a well at the town of Sashiki in Kumamoto Prefecture, Kyusyu.

The four new forms of Copepoda found in these three different wells of south-western Japan are described in the present paper.

Before going further, I wish to thank Dr. MASUZO UÉNO for his advice on many matters and for correcting the manuscript. My thanks are also due to Messrs Y. MIURA and Y. MORIMOTO who kindly sent valuable material for use in this study.

Localities with species found

Locality No. 1, wells were used as the water source, in the gathering-ground of the water-works, Himeji city, western Japan.

4, 5, 24, 26, VIII; 15, X, 1950. W.T. 17.5–18.5°C, pH 6.6–6.8.

Eucyclops miurai n. sp. (♀ 6, ♂ 4)
Acanthocyclops morimotoi n. sp. (♀ 1)
Diacyclops disjunctus (THALLWITZ) (♀ 3)
Diacyclops languidoides japonicus n. subsp. (♀ 2, ♂ 2)
Canthocamptus staphylinus JURINE? (♀ 6, ♂ 1)

Locality No. 2, Wells were used as the water source, in the gathering-ground of the water-works, Aioi-city, western Japan.

10, XII, 1950. W.T. 15.0°C

Eucyclops serrulatus (FISCHER) (♀ 4, ♂ 2)
Eucyclops miurai n. sp. (♀ 1, ♂ 6)
Paracyclops fimbriatus (FISCHER) (♂ 1)
Acanthocyclops morimotoi n. sp. (♂ 1)
Diacyclops disjunctus (THALLWITZ) (♀ 3, ♂ 1)
Diacyclops languidoides japonicus n. subsp. (♀ 7, ♂ 15)
Attheyella sp. (♀ 2)

Locality No. 3, Well, Sashiki, Kumamoto Pref., Kyusyu.

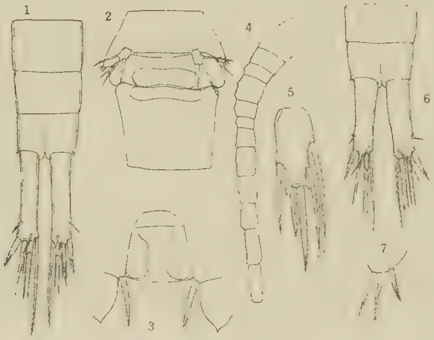
25, IX, 1945; 3, IV, 1946, W.T. 15.5°C, pH 7.4; 3, IX, 1946, W.T. 21.3°C, pH 7.0.

Macrocyclops albidus (JURINE) (♀ 5)
Eucyclops serrulatus (FISCHER) (♀ 13, ♂ 3)
Thermocyclops uénoi n. sp. (♀ 7, ♂1)

Descriptions of new species and subspecies

(1) *Eucyclops miurai* n. sp. (Figs. 1–7)

Female.—Length 0.65–0.86 mm. Body white, nauplius eye entirely absent.



Figs. 1–7. *Eucyclops miurai* n. sp. 1–5, female; 6–7, male. 1, furca, female; 2, leg 5 and receptaculum seminis; 3, connecting plate of leg 4; 4, first antenna; 5, leg 4, endopodite 3; 6, furca, male; 7, leg 6.

Furcal rami nearly parallel, very variable in length, 4.5–5.5 times as long as wide; outer margin without longitudinal row of small spines, socalled "Säge"; lateral seta inserted near end, at distal 1/5; four furcal setae and dorsal seta well-developed, their relative lengths in representative individuals is from outer to inner as follows:

Locality	I (ou.)	II	III	IV (in.)	V (dor.)
Himeji	36.8	220.8	322.0	100.0	45.0(μ)
Aioi	37.5	202.4	303.6	100.0	55.0(μ)

Inner furcal seta much longer than outer (2.2–2.7 : 1) and longer than or as long as furcal rami; outer seta spine-like, dorsal seta a little longer than outer.

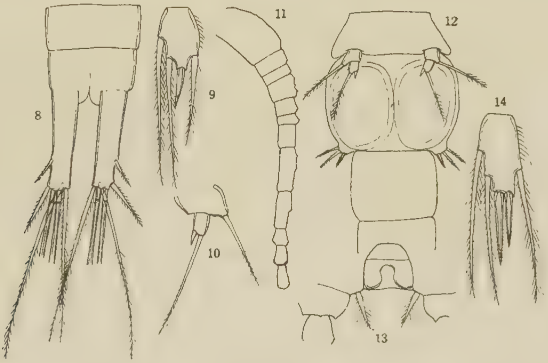
First antenna of 12 segments, very short, reaching to the posterior end of cephalothorax, without hyaline membrane on distal segments.

Four pairs of swimming-legs (leg 1–leg 4), each pair 3-segmented (formula 3,3/3,3/3,3/3,3), spine-formula 3,4,4,3; seta-formula 5,5,5,5. Leg 4, endopodite 3 long and slender, 2.0–2.7 times as long as wide; terminal spine unequal, inner spine longer than outer (1.5–2.0 : 1), but nearly or a little longer than endopodite 3 (100–125 %). Connecting plate of leg 4, leg 5 and receptaculum seminis as shown in Fig. 2, Fig. 2 and Fig. 3 respectively, resemble those of *Eucyclops serrulatus* (FISCHER).

Male.—Length 0.53–0.70 mm. More slender than female; furcal rami shorter than in female, 3.6–4.8 times as long as wide, without lateral denticles as in that of female; inner furcal seta longer than outer (2.1–3.6 : 1), and a little longer than furcal rami. Leg 6, inner spine shorter than abdominal segment 2; and also shorter than two outer setae.

Locality.—No. 1 and No. 2

This new species is allied to *Eucyclops inarmatus* KIEFER by KIEFER (1932, Zool. Anz., 101, 51–53, Figs. 3–8) described from a cave in Jugoslavia. It does



Figs. 8–14. *Acanthocyclops morimotoi* n. sp.
8–11, female; 12–14, male. 8, furca, female; 9, leg 4, endopopite 3; 10, leg 5; 11, first antenna; 12, leg 5 and leg 6; 13, connecting plate of leg 4; 14, leg 4, endopodite 3.

not different from *E. inarmatus* in the structure of furcal rami, but is evidently distinguishable from that by the first antenna of 12 segments and by the features of the endopodite 3 and the connecting plate of leg 4.

(2) *Acanthocyclops morimotoi* n. sp. (Figs. 8—14)

Female. — Length 1.44 mm. Body white, without nauplius eye.

Furcal rami relatively slender, 5 times as long as wide; lateral seta inserted at distal 1/3; inner margin without hairs; furcal setae and dorsal seta well-developed, their relative lengths in a representative individual, from outer to inner and dorsal as follows:

Locality	I	II	III	IV	V
Himeji (♀)	64.4	358.8	634.8	202.4	239.2 (μ)
Aioi (♂)	52.5	248.4	441.6	150.0	147.2 (μ)

Inner furcal seta much longer than outer (3 : 1), and longer than furcal rami (1.5 : 1), dorsal seta especially well-developed, a little longer than inner seta, and much longer than outer seta (3.7 : 1) and furcal rami (2 : 1) respectively.

First antenna 12-segmented; without hyaline membrane on distal segments.

Leg 1—leg 4; formula 3,3/3,3/3,3/3,3; spine-formula 2,3,3 3; seta-formula 4,4,4,4. Leg 4, endopodite 3 relatively wide, oval in outline, 1.4 times as long as wide, only one terminal spine 37.5 μ in length and shorter than endopodite 3 (75 %). Connecting plate simple, as shown in Fig. 13.

Leg 5 of 2-segments; seg. 1 large and broad, with a short slender seta; seg. 2 small and slender, with a short terminal seta and a small subapical spine. Receptaculum seminis not distinct.

Male.—More slender than female, length 0.91 mm. Body white, without nauplius eye as in female. Furcal rami nearly parallel, 4 times as long as wide; lateral seta located at distal 1/3. Both inner and dorsal setae much longer than outer (about 3 : 1) and longer than furcal rami as in female. Leg 4, endopodite 3 relatively slender, 1.9 times as long as wide; inner apical spine longer than outer (1.4 : 1). Leg 5 as shown in Fig. 10. Leg 6, inner spine relatively small, shorter than two outer setae.

Locality.—No. 1 and No. 2

This new species evidently belongs to the Genus *Acanthocyclops* because of the structure of leg 5. It is closely allied to *Acanthocyclops rhenanus* KIEFER (KIEFER, 1936, Zool. Anz., 115, 169–170, Figs. 1–5) described from a well in "Oberrheinischen Tiefebene", but is easily distinguished from that by rather larger body length, rather longer furcal rami, and by the presence of a single apical spine in the endopodite 3 of leg 4 in female.

(3) *Diacyclops languidoides japonicus* n. subsp. (Figs. 15—21)

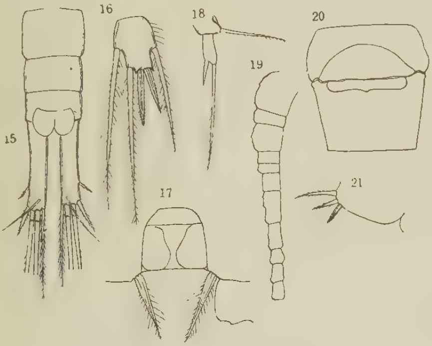
Female.—Length 0.63–0.75 mm. Body white, nauplius eye entirely absent. Furcal rami rather long, 3.6–5.2 times as long as wide; lateral seta inserted at distal 1/4; without hairs on inner margin; furcal setae and dorsal seta well-developed, their relative lengths in representative individuals, from outer to inner and dorsal as follows:

Locality	I	II	III	IV	V
Himeji	35.0	220.8	377.2	87.5	46.0 (μ)
Aioi	32.5	220.8	322.0	85.0	55.0 (μ)

Inner furcal seta much longer than outer (2.3–2.8 : 1) and longer than furcal rami (1.3–1.6 : 1); dorsal seta longer than outer and shorter than both inner seta and furcal rami.

First antenna of 11 segments, relatively short, not reaching to the posterior end of cephalothorax.

Leg 1—leg 4; formula 2,2/3,2/3,3/3,3; spine-formula 3, 3, 3, 3; seta-formula 5, 4, 4, 4 as in *Diacyclops disjunctus* (THALLWITZ). Leg 4, endopodite 3, 1.4–1.6 times as long as wide; inner apical spine scarcely longer than outer (1.09–1.22 : 1), and shorter than endopodite 3 (92–95%); three setae of endopodite 3 well-developed, extending far beyond end of inner apical spine. Structure of connecting plate of leg 4 and of leg 5 resembles that of *Diaoyclops languidoides*. Receptaculum seminis as shown in Fig. 20.



Figs. 15–21. *Diacyclops languidoides japonicus* n. subsp. 15–20, female; 21, male. 15, furca, female; 16, leg 4, enpopodite 3; 17, connecting plate of leg 4; 18, leg 5; 19, first antenna; 20, receptaculum seminis; 21, leg 6, male.

Male.—Length 0.59–0.68 mm. Furcal rami more slender than in female, 3.7–5.2 times as long as wide; inner furcal seta longer than outer (2.3–2.9 : 1) and longer than furcal rami as in female. Structures of leg 1—leg 4 as in female.

Locality.—No. 1 and No. 2

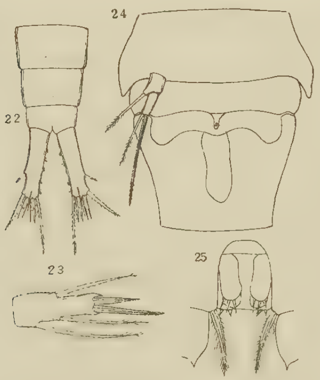
This new subspecies belongs to *languidoides*-group in the segmentation of the first antenna and leg 5. It is also closely allied to *Diacyclops languidoides zschokkei* (E. GRAETER), which was reported from a cave of "Schweizer Jura" (E. GRAETER, 1911, Arch. f. Hydrobiol., 6, 1–48; P. A. CHAPPUIS, 1924, Arch. f. Hydrobiol., 14, 1–88), but is distinguished from that by the lengths of the furcal rami and the inner furcal seta, and by the structure of the endopodite 3 of leg 4.

(4) *Thermocyclops uénoi* n. sp. (Figs. 22—25)

Female.—Length 0.75–1.20 mm. Body white and with distinct red nauplius eye. Furcal rami remarkably divergent, 3.5–4.6 times as long as wide, and provided with 4–5 bundles of fine hairs on inner margin; lateral seta located at distal 1/3; inner furcal seta longer than outer (1.3–1.8 : 1) and usually shorter than furcal rami.

First antenna of 17 segments, relatively short, extending to the posterior end of body somite 2.

Leg 1—leg 4, formula 3,3/3,3/3,3/3,3; spine formula 2, 3, 3, 3; seta-formula 4, 4, 4, 4. Leg 4, endopodite 3, 2.0–2.7 times as long as wide; inner apical spine longer than outer (1.4–1.8 : 1), but shorter than endopodite 3 (88–95%). Connecting plate of leg 4 with three pairs of rounded prominences; 3 slender spines on anterior and 2 small, stout processes on top of posterior prominence respectively, but no appendages on top of middle.



Figs. 22–25. *Thermocyclops uénoi* n. sp. 22–25, female. 22, furca; 23, leg 4, endopodite 3; 24, leg 5 and receptaculum seminis; 25, connecting plate of leg 4.

Leg 5 of 2 segments; seg. 2 rather slender, inner terminal spine much longer than outer seta (1.7 : 1). Receptaculum seminis hammer-shaped, resembling that of *Thermocyclops hyalinus* (REHBERG), but lateral part rather broader than in the latter.

Male—Length 0.86 mm.

Locality.—No. 3.

This new species is closely allied to *Thermocyclops trichophorus* (KIEFER) described from a well in the Buitensorg Botanical Garden in Java (KIEFER, 1930, Zool. Anz., 90, 82–92; 1934, Arch. f. Hydrobiol., Suppl. 12, 519–615), but is distinguishable from that by the features of the furcal setae and structure of the connecting plate of leg 4 and also by the receptaculum seminis.

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Vol. 1, No. 2, November 30, 1952.

STUDIES ON THE MIDGUT-GLAND IN INVERTEBRATA

III. Cytochemical Reactions of some Midgut-Gland Cells in Snail, Crab and Clam.

(*With 1 Plate*)

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The midgut-gland, one of the most important digestive organs in the invertebrata, has been studied as to its organization and function by many investigators, but the research has not been as comprehensive as that for the liver of the vertebrata.

Many previous investigators (1), who studied the midgut-gland in the invertebrata, called one type of constituent cell of the midgut-gland of the snail the lime cell, the one in the crab the fiber cell, and the one in the clam the young cell. These cells seem to have been named from the functional viewpoint. Because this terminology has been used only in the case of the invertebrata, there would be many people who still consider that the midgut-gland is a special organ of the invertebrata.

The following report shows the results of the author's cytochemical investigations on the midgut-gland cells. He has found that the constituents of the cells, which have been given such different names, are similar in that a great deal of ribonucleic acid (RNA) is found in each of the three types of cells.

The results seem to be very important in that they contribute greatly to understanding the function of the midgut-gland of the invertebrata.

(The author expects many critical comments by the readers of this study).

This research, for the most part, was carried out at the Tokyo University of Literature and Science. The author wishes to express his sincere thanks to Prof. S. TAKATSUKI, who gave him kind guidance. Thanks are also due to Dr. O. ICHIKAWA and A. SHIBATANI (Medico-Biological Institute of Minophagen Pharamoceutical Co.), who gave him valuable suggestions and kindly gave him the crystalline ribonuclease (RNA-ase), and to M. NAKAJIMA,

who instructed him in valuable discussions. And the author is very thankful to Prof. Y. OKADA, Dean of this Faculty, who has kindly afforded him the opportunity for the present publication of this paper.

Materials and Methods

The following three specimens were used:

Snail……………………*Euhadra sp.*
Crab……………………*Hemigrapsus sanguineus.*
Clam……………………*Meretrix lusoria.*

Snails were collected from the Botanical Garden attached to the Tokyo University (Tokyo); crabs were collected from the Shimoda Marine Biological Station attached to the Tokyo University of Literature and Science (Shizuoka Pref.); clams were collected from the vicinity of Tsu City (Mie Pref.).

The specimens were fixed as soon as they were collected. Tissues were prepared by immersion in 10% neutral formalin or CHAMPHY's fluid. After dehydration with alcohol, the tissues were infiltrated with paraffin, and were embeded in paraffin, and then cut into sections of 5μ thickness.

The following staining procedures were performed:

1) *Staining with* MAYER's *hæmalaum and eosin.* The sections were deparaffined, and were stained in MAYER's haemalaum and 1% eosin alcoholic solution. Dehydration, clearing, and mounting were done in the usual manner.

2) *Staining with thionin.* The sections were deparaffined, and then stained, in 0.5% thionin aqueous solution for from 1 to 48 hours. The stained sections were discriminated in 70% alcohol, dehydrated, cleared, and mounted in neutral balsam.

3) *Staining with toluidin blue.* The possible presence of mucopolysacchorides, which should be conjugated with sulfuric acid, was examined by staining the sections in 1% toluidin blue aqueous solution for from 1 to 3 hours. After staining, the sections were discriminated in 60% alcohol, dehydrated, cleared in xylol, and mounted in neutral balsam.

4) *Staining with pyronin-methylgreen.* The sections were stained in pyronin-methylgreen fluid for 20 minutes, discriminated in 70% alcohol, dehydrated in isopropyl alcohol, cleared in xylol, and mounted in neutral balsam.

5) *The* FEULGEN's *reaction procedure.* The possible presence of disoxyribonucleic acid (DNA) was examined by the FEULGEN's reaction procedure.

6) *The treatment with RNA-ase on the metachromatic substance of the cell.* After deparaffining, the sections were incubated in 0.10% RNA-ase aqueous solution at 60° C. for 1 hour. The RNA ase was extracted from cow's spleen by BRACHE's method. As a control for this procedure, the second groups of the

sections were incubated in water at 60°C. for 1 hour. Then sections of both groups were stained with thionin or pyronin-methylgreen.

In the staining procedure, the sections prepared in each experiment were stuck on the same glass slide, and then were uniformly stained.

Observations

1). *The reaction with* MAYER'S *hœmalaum and eosin.* The cytoplasm in the lime cells of the snail contains many large granules that were not colored in haemalaum and eosin, indicating a basophil reaction (Fig. 1). Generally speaking, the lime cells are larger than the cells which are called enzyme cells; especially, their nuclei are much larger, spherical or oval in shape, and are deeply colored by haemalaum. Each nucleus has a large spherical shaped nucleolus. On the other hand, enzyme cells and all other parenchymatous cells have smaller nuclei and no nuceoli.

The cytoplasm in the fiber cells of the crabs, which showed a basophil reaction, incloses the fioriform cytoplasm in the anterior region, and has some large vacuoles in the basal region. There was acidophil cytoplasm in the periphery of the vacuoles (These vacuoles should be the fatty granules) The big nucleus lies near the center of the cell and has a large oval nucleolus. But all the parenchymatous cells, except the young cells, that constitute the midgut-gland have scattering cytoplasm severally and they show acidophil reaction rather than a basophil reaction. The nuclei of these cells are smaller and have no nucleoli.

The young cells in the *Lamellibranchiata*, such as clams, have basophil cytoplasm. On the other hand, all the parenchymatous cells in the midgut-gland, except the young cells, have no basophil cytoplasm and have small nuclei without nucleoli, while the nucleus of the young cell is large and spherical and has a nucleolus.

The author investigated the basophil cytoplasm of these cells in the following cytochemical tests.

2). *The reaction with thionin.* The substance which lies in the fibriform cytoplasm in the fiber cell shows a metachromatic reaction with thionin, but the cytoplasm which surrounds the fatty granules that lie near the basal region of the fiber cell shows no metachromatic reaction with this staining solution (Fig. 2). The cytoplasm in all other parenchymatous cells, which constitutes the midgut-gland in the crab, show no metachromatic reaction.

Similar reactions were observed in the cytoplasm of the lime cells, but all the other cells, with the exception of the lime cells, show metachromatic reaction. (Fig. 3).

The cytoplasm of the young cells show a metachromatic reaction, but all the other cells, with the exception of the young cell, show no metachromatic reaction.

The cytoplasm in the duct cells of the midgut-gland shows a remarkable metachromatic reaction. The author will publish the data on these reactions at the earliest opportunity.

3). *The reaction with toluidin blue.* Those parts of the cytoplasm which are mentioned above show no metachromatic reaction with toluidin blue. The cytoplasm was very slightly colored blue.

4). *The reaction with pyronin-methylgreen stain.* The cytoplasm and the nucleolus, which showed the metachromatic reaction with thionin stain, show a pyroninophil reaction. The cytoplasm of all the other cells shows only a slightly pyroninophil reaction around the nuclei, while the chromatins and the nuclear membranes show a strong methylgreenophil reaction.

5). *The results with* FEULGEN'S *reaction.* With FEULGEN'S reaction, the nuclear membranes and the chromatins which previously showed a methylgreen reaction, were positive, but the cytoplasm, which showed the pyroninophil reaction, was negative.

6). *The reaction after treatment by the RNA-ase procedure.* When the RNA-ase treated sections were placed in thionin solution, they showed no metachromatic reaction in those parts of the cytoplasm that had shown the metachromatic reaction when treated with thionin stain alone. Also, when these sections were placed in pyronin methylgreen stain, they showed no pyroninophil reaction.

But in the control experiment, the tissue sections that were incubated in water at 60°C. for 1 hour showed the remarkable metachromatic reaction in the cytoplasm, when stained with thionin.

Discussion

In the present study, the reactions of lime cells, fiber cells, and young cells have been investigated by a number of cytochemical methods. The results of these experiments are shown in Table 1.

The cytopl sm in the lime cells, fiber cells, and young cells showed a basophil reaction, while all the other cells that constituted the midgut-gland do not show a basophil reaction. Moreover, the cytoplasm which showed the basophil reaction also showed the metachromatic reaction when stained with thionin dye.

The metachromatic cytoplasm of these cells does not show a metachromatic reaction with toluidin blue. According to the results of the researches

Table 1. Staining reactions of lime cell, fiber cell, young cell, and associated parenchymatous cells.

Stain				Haemalaum and eosin	Thionin	Touidin blue	Pyronin methylgreen	Feulgen's reaction	Effect of RNA-ase.
Euhadra sp.	lime cell	nucleus	chromatin	purplish red	blue	blue	green	+	—
			nucleolus	red	purple-red	light-red	red	—	+
		cytoplasma		purplish red	blue	blue	red	—	+
	other cells	nucleus	chromatin	purplish blue	blue	blue	green	+	—
			nucleolus	—	—	—	—	—	—
		cytoplasma		light yellow	light blue	light blue	—	—	—
Hemigrapsus sanguineus.	fiber cell	nucleus	chromatin	purple	blue	blue	green	+	—
			nucleolus	red	purple-red	light blue	red	+	—
		cytoplasma		purplish red	purplish red	light blue	red	—	+
	other cells	nucleus	chromatin	purple	blue	blue	green	—	—
			nucleolus	—	—	—	—	—	—
		cytoplasma		light reddish yellow	light blue	light green	—	—	—
Meretrix lusoria.	young cell	nucleus	chromatin	purple	blue	blue	green	+	—
			nucleolus	red	purple	blue	red	—	+
		cytoplasma		purple	blue	blue	red	+	+
	other cells	nucleus	chromatin	purple	blue	blue	red	+	—
			nucleolus	—	—	—	—	—	—
		cytoplasma		light reddish yellow	light blue	light blue	—	—	—

of SHIBATANI (3, 4), OHNO, KAWAI and NOTSUKI (5) the distinctly metachromatic reaction with thionin is not due to the mucopolysaccharides which may be conjugated with sulfuric acid.

SHIBATANI (3, 4) showed in his studies that where the metachromatic reaction with thionin staining occurs is the same place where RNA exists. And when the sections are stained in pyronin-methylgreen, those areas where the above mentined metachromatic reaction occures show a pyroninophile reaction, but no phyroninophil reaction appears after treatment with crystalline RNA-ase. These reactions should be caused by the presence of RNA.

The author considers that there may be a large amount of RNA in the cytoplasm in the lime cell because, although VON KOSSA's, GRANDIS' and other methods have been adopted, lime has scarely been found in the cytoplasm (6).

Also the same part of the cell showed very remarkable metachromatic and pyroninophil reactions. NAKAJIMA (7) found that the cytoplasm in the lime cell is rich in alkaline phosphatase.

The fiber cell in the midgut-gland of crabs was so named because it has a basophil fibriform cytoplasm. According to the above mentioned results, it seems to have an amount of RNA in the basophil cytoplasm.

The young cell was named by YOUNG (8), whose histological study ports the presence of the cell divisions in these cells. A similar phenomenon was also observed by HASHIMOTO (9), who found the cell divisions in the young cells of *Cristria plicata spatiosa* (CLESSIN), although he could not find them in the other cells that constituted the midgut-gland. From the present results, it will be naturally concluded that the young cells must contain an appreciable amount of RNA.

SCHULTZ and CASPERSSON (10) show that RNA is abundant in the cytoplasm of rapidly growing plant and animal tissues, but not in the homogenous tissues. Tumor cells have also been found to have contained an abundance of RNA by CASPERSSON and his associates (11) and by MITCHELL (12).

DAVIDSON and WAYMOUTH (13) have found evidence suggesting that rapidly growing embryonic tissues are characterized by both a high nuclear DNA content and a high cytoplasmic RNA content. HAMMARSTEN and his associates (14) have well confirmed the presence of RNA in the cytoplasmic masses of the rat liver by their failure to absorb ultraviolet light after treatment with crystalline ribonuclease.

WISLOCKI and DEMPSEY (15) reported that the megakaryocyte has a basophil cytoplasm which should be due to the occurrence of RNA.

McSHAN, DAVIS, SOUKUP and MEYER (16) report that the pigeon crop gland, when stimulated by the injection of pituitary lactogenic hormon, gains rapidly in weight, and that this growth is accompanied by an increase in the concentration of RNA and in the activity of succinic dehydrogenase, but that DNA increases to a much smaller extent.

These results suggest that the functional activites of the lime cell, fiber cell, and young cell are different from those of all other parenchymatous cells in that all three contain an amount of RNA, and that therefore they probably have a similar functional activity.

Summary

Various cytochemical methods have been adopted for the staining of lime cells, fiber cells, and young cells.

1) These cells have a basophil cytoplasm, and each has a large spherical or oval nucleus which contains a nucleolus.

2) The basophil cytoplasm of each kind of cell shows a metachromatic reaction with thionin stain, but shows no metachromatic reaction with toluidin blue stain.

3) The metachromatic cytoplasm shows a pyroninophil reaction.

4) The metachromatic reaction which occurred with thionin should not be caused by the presence of the mucopolysaccharides, which may be conjugated with sulfuric acid, but should be caused by the presence of RNA.

5) The place where the metachromatic reaction occurred was negative with Feulgen's reaction, and further the metachromatic reaction failed to appear after treatment with crystalline RNA-ase.

6) From these results, although these cells have been given different names—lime cell, fiber cell, and young cell—these cells seem to have certain basic structural and cytochemical characteristics.

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Fig. 1. Lime cell of the Snail.
Haemalaum-Eosin staining. ×86.4

Fig. 2. Fiber cell of the Crabs.
The metachromatic reaction with 1% thionin. ×432

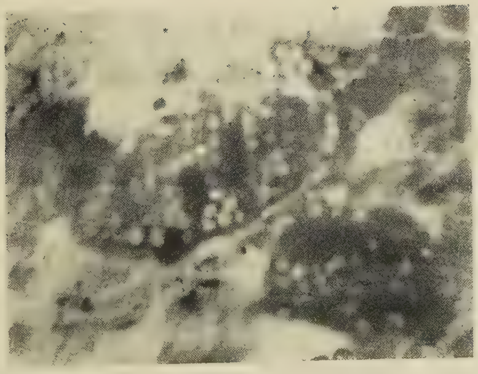

Fig. 3. Lime cell of the Snail.
The metachromatic reaction with 1% thionin. ×432

TSUJII—Studies on Midgut gland in Invertebrata—Photomicrographs of cells

Report of Faculty of Fisheries,
Prefectural University of Mie,
Vol. 1, No. 2, November 30, 1952.

SUR LA PHOTOTAXIE DES POISSONS ISOLES

(*Avec 2 tableaux et 5 figures*)

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J'ai montré, dans un autre rapport (OZAKI) que j'ai presenté, qu' il y a une grande différence entre la phototaxie des poissons en groupe et celle des poissons isolés et qu'il semble que cette différence se produise par le fait même qu'ils sont en groupe ou isolés. Nous nous sentons donc obligés de faire des recherches plus minutieuses sur le comportement des poissons sous chacune de ces deux conditions. Dans ce présent rapport, j'exposerai les résultats acquis au cours de mes expériences sur les poissons isolés.

Il va sans dire qu'il y a plusieurs méthodes à suivre dans cette sorte de recherches. Or, comme nous nous appliquons uniquement à examiner les influences des ondes lumineuses sur les poissons, les expériences dont je vais vous rendre compte ont été constituées sur le même domaine. Observer comment réagissent les poissons contre chacune des huit couleurs, voilà le procédé de mes recherches.

Ces recherches ont été faites dans l'Institut de Recherches Ichthyologiques, près de Shimoda, Préfecture de Shizuoka, Japon. J'ai l'honneur de témoigner ici mes profonds remerciments envers M. N. Y. KAWAMOTO, directeur de cet Institut, pour les précieuses aides qu'il a bien voulu me prêter au cours de ces recherches.

Matériaux d'expérience

Les poissons que j'ai soumis en expérience sont des *Girella punctata* et des *Mugil cephalus* qu'on avait pris au bord de la mer, près de l'Institut. La longueur de leur corps est approximativement de 2,5 à 3,5 cm. Ces poissons étaient nourris dans un réservoir pendant plusieurs jours avant l'expérimentation.

Méthode d'expérience

Nous avions préparé un réservoir en forme cylindrique, autour duquel sont avancées, à distance égale, huit petites chambres, éclairées chacune par

un filtre monochromatique différente de couleur en fabrication du KAGAKU-KENKYUSHO.

Je prends un seul de ces poissons et je le laisse nager dans ce réservoir faiblement éclairé d'abord pour le faire adapter à cette nouvelle condition. Après vingt minutes environ j'allume les lampes. Le poisson nage en visitant les chambres l'une après l'autre. J'observe l'ordre de sa visite en registrant la couleur de la lumière qui éclaire la chambre ; cette observation est divisée par minute et continue pendant seize minutes. Il arrive que le poisson reste longtemps dans la même chambre. Pour ce compte, il faut savoir à l'avance combien de chambres il visite d'ordinaire en une minute. Cette expérience préliminaire nous apprend qu'il en visite environ six. Je considère donc qu' il visite une chambre toutes les dix secondes et que le séjour de dix secondes indique une fois de visite. J'appelle le nombre des visites compté ainsi "Fréquence totale de visitation (T)". Par conséquent, s'il séjourne moins de dix secondes, je compte une fois de visite, moins de vingt minutes, deux fois de visite, ainsi de suite. Le nombre des visites compté sans considération de la durée du séjour, je l'appelle "Fréquence de visitation (F)". Ensuite, le nombre compté par les couleurs des chambres qu'il visite en une minute, je l'appelle simplement "Nombre des couleurs visitées (C)". Je registre chacun de ces trois nombres par minute et j'examine la phototaxie des poissons isolés en relation avec cette variation des nombres.

La température de l'eau du réservoir est maintenue à 16°~18°C au cours de l'expérience sur les *Mugil cephalus* faite en hiver, elle est élevée jusqu'à 20°~24°C afin de connaître l'effet de la température de l'eau. Quant aux *Girella punctata*, l'expérience a été faite en automne et la température de l'eau était maintenue à 23°~27°C. Elle était de 16°~18 C à l'expérience sur les effets des produits pharmaceutiques ou du pH.

Résultats expérimentaux

I. Chez le *Girella punctata*.

Les résultats expérimentaux acquis sur cinquante *Girella punctata* essayés un à un, sont indiqués dans le Tableau 1 et dans la Figure I. La fréquence totale (T) est au commencement à 8,2, décroît à mesure que le temps passe, et descend jusqu'à 6,0 après quinze minutes. La fréquence de visitation (F) commence par 7,2, montre ensuite une diminution rapide dans trois ou quatre minutes, approche de la courbe indiquant le nombre des couleurs, et après quinze minutes, finit par descendre à 3,1. Le nombre des couleurs (C), étant de 4,7 au début, trace une courbe presque parallèle à celle de T et descend

Tab. 1. Les variations des trois valuers sous la condition normale chez le *Girella punctata*. (Temp. de l'eau 23°～27°C.)

min.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T	·82	7.8	7.5	7.2	6.7	6.8	6.7	6.5	6.0	6.3	6.3	5.9	5.7	5.8	5.7	6.0
F	7.2	7.1	6.3	5.8	4.7	4.8	4.3	4.2	3.7	3.9	4.3	4.1	3.5	3.6	3.1	3.1
C	4.7	4.7	4.5	4.2	3.8	3.7	3.3	3.5	2.9	3.3	3.2	2.8	2.8	2.9	2.5	2.7

jusqu'à 2,7 à la fin de quinze minutes. La différence entre T et F (D_1) indique la durée du séjour d'un poisson dans la chambre. Il semble que D_1 augmente, dans trois ou quatre minutes, d'une manière un peu considérable. De là, on peut présumer que la tendance du poisson à un long séjour devient le plus remarquable vers cette période.

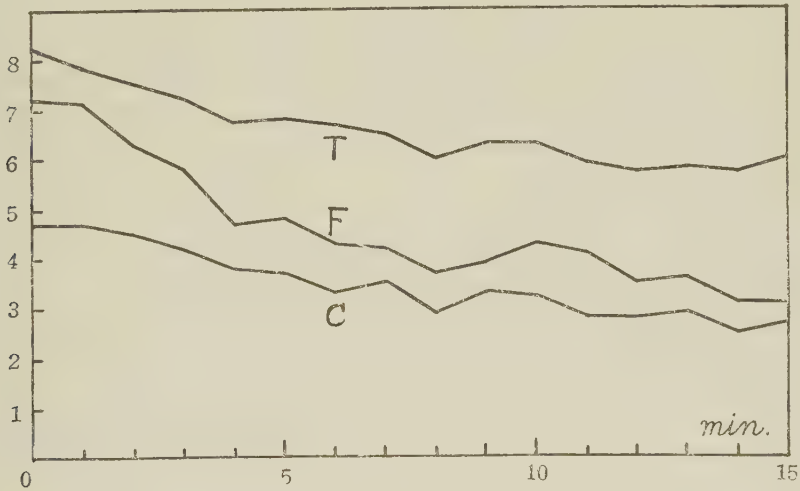

Fig. 1. Les variations des trois valeurs sous la condition normale chez le *Girella punctata*. (Temp. de l'eau : 23°～27°C)

La différence entre F et C (D_2) indique le nombre des visites rendues à une même chambre pendant une minute. Or, je pourrais croire que D_2 est proportionnel à l'excitation mentale du poisson. D_2 diminue à mesure que D_1 augmente. Voyant ces cinq chiffres qui varient, on peut connaître qn'au début T et D_2 sont grands contrairement à D_1 ; ce qui montre que le poisson visite les huit chambres au hasard, sans aucune distinction. Je constate par le fait même que le poisson, dans les nouvelles circonstances, réagit

contre la lumière des lampes subitement allumées et qu'il tombe daus une sorte de crainte ou de confusion psychologique. Mais cette agitation mentale s'apaise à mesure que le temps passe, et après quinze minutes commence à apparaître la tendance rester longtemps dans une même chambre et en même temps D_2 décroît. Ensuite, si C diminue, c'est que le poisson manifeste la tendance à rester plus longtemps dans une chambre de certaine conleur. (Cette couleur est à la choix de chaque poisson.) Il ne faut pas oublier ici que T est de 6,0, ce qui permettra de dire que le poisson reste presque toujours dans une même chambre pendent toute une minute.

Cette expérience a été faite dans l'eau dont la température était á 23° ~27 C. Quant aux effets de la température, j'exposerai quelques résultats de mes expériences faites sur les *Mugil cephalus* d'abord dans l'eau de 16 ~18°C et puis dans celle de 20°~24°C.

II. Chez le *Mugil cephalus.*

On peut voir, dans le Tableau 2 et dans la Figure 2, les résutats que j'ai acquis par les mêmes procédés et qui diffèrent un peu de ceux du cas précédent. T est de 5,0 au début et diminue graduellement jusqu'à 3,1 après quinze minutes, après avoir atteint le maximum de 5.7 au bout d'une minute. Telle baisse de T ne s'est pas connue chez le *Girella punctata.* Nous avons registré le chiffre de 6,0 comme valeur presque constante de T, c'est-à-dire que

Tab. 2. Les variations des trois valeurs sous la condition normale chez le *Mugil cephalus.* (Temp. 16°~18°)

min.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T	5.0	5.7	5.4	4.8	4.9	4.4	4.4	4.1	3.7	3.4	3.7	3.2	3.2	3.2	3.4	3.1
F	4.4	5.2	4.5	4.0	4.0	3.4	3.0	2.8	2.6	2.0	2.4	2.3	2.1	1.9	2.0	1.6
C	4.0	3.8	3.6	3.4	3.4	2.9	2.6	2.4	2.2	2.0	2.1	1.7	1.8	1.7	1.7	1.4

le *Girella punctata* s'approchait de la lumière et qu'il y restait à toute heure. Tandis que le *Mugil cephalus* nage la plupart du temps dans les ténèbres au milieu du reservoir et ne visite que rarement les chambres. De plus, cette fréquence totale de visitation diminue de plus en plus et finira par baisser au zéro, si l'on met encore plus de temps. F est de 4,4 au début, ensuite diminue peu à peu après avoir atteint le maximum de 5,2 au bout d'une minute, et, dans trois ou quatre minutes, cela approche de la courbe C plutôt que de la courbe T. Depuis ce moment, la différence de valeur entre F et C ne dépasse

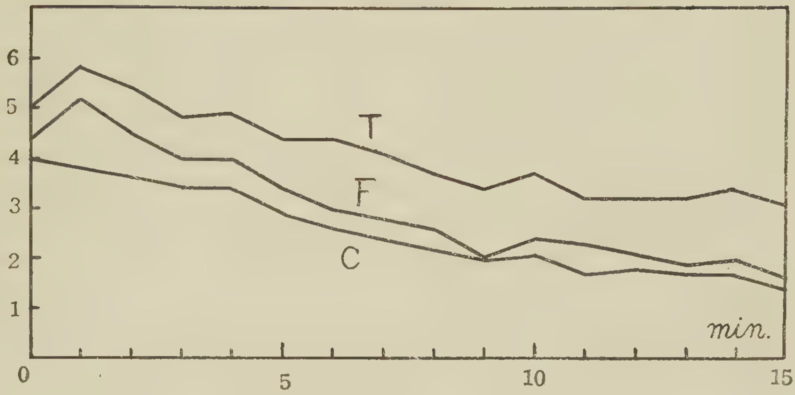

Fig. 2. Trois valeurs sous la condition normale chez le *Mugil cephalus*. (Temp. 16°~18°C)

plus 0,5. C commence par le chiffre de 4,0, diminue toujours et, après cinq minutes, il devient à peu après parallèle à la courbe T.

D_1 augments peu à peu et, après avoir excédé la valeur de 1,0 au bout de cinq minutes, il continue encore à monter. D_2, après avoir marqué son maximum au bout d'une minute, reste au-dessous de 0,5 à partir de 5 minutes.

Il y a deux grandes differences suivantes entre les données obtenues chez le *Girella punctata* et chez le *Mugil cephalus*: (1) Différence de la valeur de T.—Chez le *Girella punctata,* T est près de 6,0 et chez le *Mugil cephalus,* T atteint 3,0. Cette différence signifie que le premier approche volontairement de la lumière, tandis que le dernier manifeste la tendance a s'éloigner de la lumière. Ce phénomène apparaît également dans une autre expérience: si l'on allume seulement une lampe du réservoir et qu'on y entre dix poissons de chaque espèce, on voit que, chez les *Girella punctata,* le groupement sous la lampe se grossit de plus en plus au bout de huit ou neuf minutes et que, chez les *Mugil cephalus,* les poissons se dispersent de plus à mesure que le temps passe. (2) Différence du maximum de T.—Chez le *Mugil cephalus,* ce maximum se manifeste au bout d'une minute. Ce que signifie ce phénomène, je suis encore loin de le déterminer. Seulement je suppose qu'il s'agisse ici du temps qu'il faut pour que le poisson se calme après la première excitation causée par l'éclairage.

III. Effet de la température de l'eau. (Chez le *Mugil cephalus*).

Le poisson est généralement fort agissant à la haute température, qui

lui donne en effet une grande activité physique et psychologique. Il y a donc deux sortes d'excitation, celle de la nature physique et celle de la nature psychologique. Quand on observe le mouvement actif des poissons, il faut y faire cette distinction.

A la température de 20° à 24° C, les variations des trois valeurs sont indiquées dans la Figure 3. En comparaison avec la Fig. 2, on constate dans la Fig. 3 les faits suivants: 1° Tous les chiffres portent une plus grande valeur. 2 D_2 est grand. 3° D_1 exède D_2 après que plus longtemps. Pareille augmentation des valeurs sont naturelle à la haute température. Le fait que j'ai mentionné troisièmement nous apprendra que le poisson a besoin plus de temps à la haute température pour apaiser l'agitation causée par l'éclairage. Mais, comme D_2 est toujours plus grand dans ce cas que dans la Fig. 2, on peut dire que l'agitation susdite est aussi plus profonde.

Si la température de l'eau est un facteur important pour la vie du poisson, la température depuis 20° jusqu'à 24°C n'est jamais anormale. L'élévation de la température excite le poisson physiquement et psychologiquement, mais, comme vous le verrez dans la suite, cette excitation n'est pas de la même nature que celle qui se produit sous l'effet de l'alcool, de l'acide, de l'alcali, pour la raison qu'ici D_1 exède D_2 toujours. J'oserai dire seulement qu'à la haute températuture, le poisson subit par l'éclairage une plus grande excitation mentale qu'à la basse température.

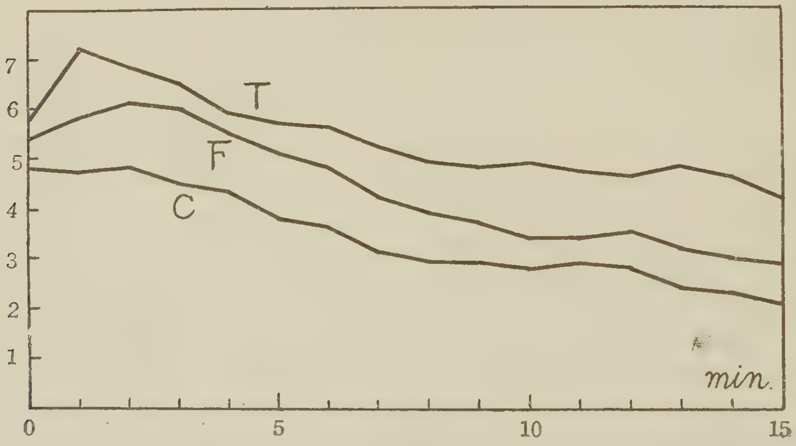

Fig. 3. Effet de la température chez le *Mugil cephalus*.
(Temp. 20∼24°C)

IV. Effet de l'alcool. (Chez le *Mugil cephalus*).

La température de l'eau était déterminée à 16°∼18°C. Après avoir jeté

dans l'eau quelques gouttes d'alcool, j'y ai mis le poisson, et, cinq minutes après, j'ai allumé les lampes ; voici commence la détermination. Les résutats obtenus sont registrés dans la Figure 4. En général, tous les chiffres ont une grande valeur. La courbe T atteint son point culminant au bout de trois minutes, descend ensuite. La courbe F atteint aussi son sommet au bout de quatre minutes et se dessine parallèlement à la courbe T, mais la courbe F n'approche pas de la courbe C comme on voit dans les Figures 1, 2, 3. La courbe C est un peu irrégulier, en marquant un sommet au bout de trois minutes. Vous voyez que D_2 est toujours plus grand que D_1. Ces faits montrent que, sous l'effet de de l'alcool, le poisson subit une assez violente excitation et que ce trouble psychologique ne peut pas être apaisé pendant les premiéres quinze minutes au moins. Du fait que D_2 exède toujours D_1, on pourrait dire que la haute température stimule le poisson autant que l'alcool, mais d'une manière tout à fait différente. En d'autres termes, la haute température et l'alcool, quoi qu'ils soient stimulants tous les deux, ne produisent pas le même effet.

Quand la concentration de l'alcool est au degré, le poisson ne reste plus à l'état d'excitation, mais il se plonge dans l'état d'engourdissement. Sa façon d'agir est tout à fait en désordre. Mais le progrès en est divers selon le degré de la concentration de l'alcool.

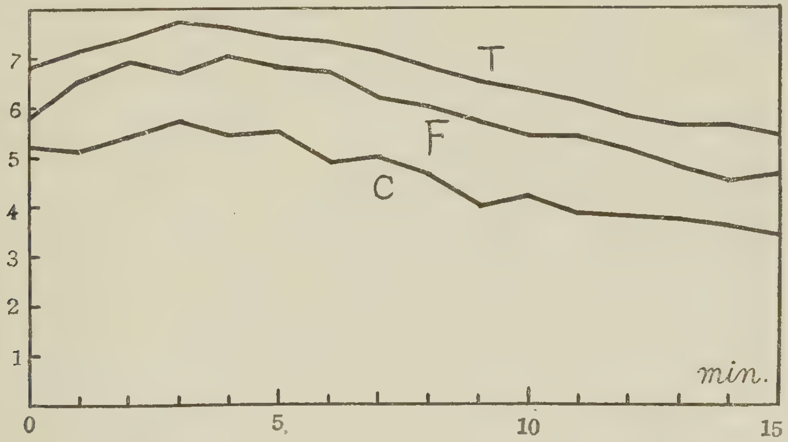

Fig. 4. Influence de l'alcool chez le *Mugil cephalus*.
(Temp. 16°～18°C)

V. Influence du pH. (Chez le *Mugil cephalus*)

Le pH, de même que la température, est un facteur important pour la vie du poisson. Nous avions déjà fait connaître (1) que la courbe marquant les relations du groupement des poissons avec la longueur de l'onde lumineuse devient irrégulière à mesure que le pH de l'eau s'éloigne de celui de l'eau de

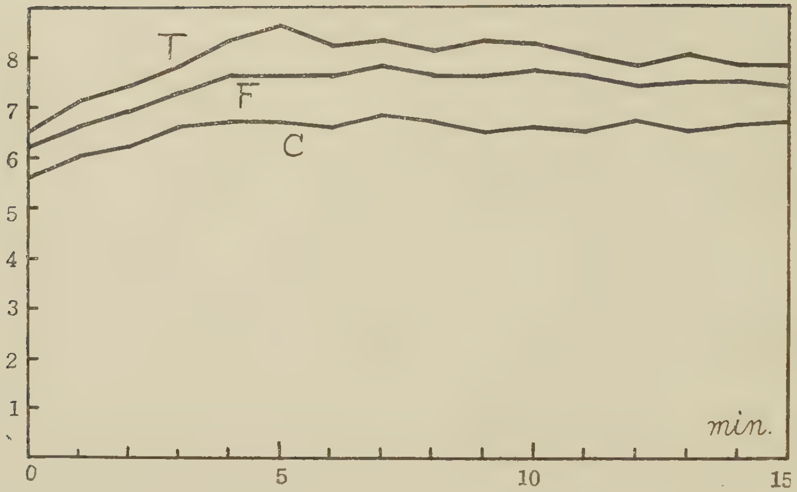

Fig. 5. Effet du pH=6.5 chez le *Mugil cephalus*.
(Temp. 16°~18°C)

mer. Comme nous l'avions supposé ailleurs (KAWAMOTO et al.), la variation du pH aurait donné une influence quelconque sur le groupement des poissons et ceux-ci auraient fini par se disperser. Maintenant nous allons examiner l'influence du pH sur les poissons isolés, en nous référant aux variations des trois chiffres.

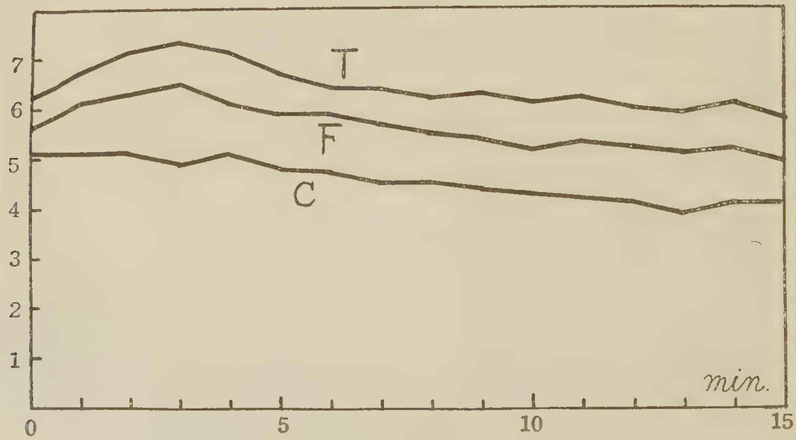

Fig. 6. Effet du pH=9.5 chez le *Mugil cephalus*.
(Temp. 16°~18°C)

Vous trouverez, dans la Fig. 5 et la Fig. 6, les résultats de nos deux expériences déterminant le pH, l'une à 6,5 (6,0~7,0; HCl), l'autre à 9,5 (9,0~10,0; Na_2CO_3). Nous avons commencé la détermination cinq minutes après la mise du poisson dans l'eau contenant le pH déterminé. Dans les deux cas, la

différence de la valeur du pH, en comparaison de celui de l'eau de mer (approximativement 8,0), est environs de 1,5, mais l'irrégularité de la courbe est plus remarquable au pH déterminé à 6,5 qu'au pH déterminé à 9,5. Il ne faut pas d'ailleurs ignorer que, dans le premier cas, T diminue peu et que D_1 est moi dre que D_2. Nous pouvons donc croire que, sous ces conditions, l'excitation psychologique du poisson doit être assez profonde. Avec le pH déterminé à 9,5, il n'en est pas de même: D_1 est presque égal à D_2, et T diminue même peu à peu. Il semble que le poisson résiste à l'alcali plus fortement qu'à l'acide.

Considérations

Nous devons considérer d'abord la signification des valeurs des trois chiffres et ensuite la correspondance qui existe entre les variations relatives des trois chiffres et la psychologie des poissons qui se comportent.

Quand le poisson reste dans une chambre pendant une minute, trois valeurs sont: $T=6$, $F=1$, $C=1$. Alors si T est plus grand que 6, cela veut dire que le poisson fréquente plusieurs chambres; si au contraire T est moins grand que 6, cela nous apprend que le poisson reste à l'ombre sans fréquenter aucune chambre. Quand le poisson visite plusieurs chambres, F est aussi grand, et dans le cas contraire F devient petit. Il en résulte qu'avec peu de différence entre T et F, le poisson est au mouvement pressé et qu'il demeure souvent dans une chambre si la différence en est grande. T approche de 6 et en même temps F décroît à mesure que le poisson séjourne dans une seule chambre. Il n'est pas possible que F se monte autant que T. Vous en trouverez l'exemple chez le *Girella punctata* (Fig. 1).

Dans la Figure 1, on trouve le plus grande différence de valeur entre T et F dans dix ou quinze minutes. A la période où le poisson demeurant à l'ombre, ne fréquente pas de chambres, T devient plus petit que 6 et, ainsi que C, F diminue. C'est bien ce que l'on voit chez le *Mugil cephalus* (Fig. 2) à partir de dix minutes jusqu'à quinze minutes. Le poisson, sorti de l'ombre, entre dans la chambre de temps à autre. S'il y a une grande différence de valeur entre T et F, cela veut dire que le poisson entre dans une chambre et y demeure quelques temps. S'il n'y a qu'une petite différence entre F et C, cela indique qu'il n'entre pas à plusieurs reprises dans la même chambre pendant toute une minute. C'est aussi ce que l'on voit au même endroit de la Fig. 2.

Si les valeurs absolues des trois chiffres sont toutes grandes, c'est que le poisson est excité. Il y a entre ces trois valeurs des relations intimes l'une avec l'autre. Quand T dépasse 6, F et C doivent être également grands. De

plus, si D_1 est petit, on peut juger que le poisson agit rapidement presque sans s'arrêter. Dans les expériences sur le pH et sur l'alcool, les trois valeurs sont toujours grandes et D_1 est petit. Cela montre que les effets du pH ou de l'alcool diffèrent de celui de la température.

De ce qui précède, on peut tirer les conclusions suivantes:

1. Excitation psychologique. Toutes les valeurs sont grandes, mais D_1 est souvent plus grand que D_2. (Fig. 3, 10~15 minutes.)

2. Confusion psychologique. Les trois valeurs sont grandes; T et F ont des valeurs approximatives; D_1 est plus petit que D_2. (Fig. 4, 5, 6)

3. Quiétude psychologique. Les trois valeurs deviennent petites, mais la valeur de T est variante selon l'espèce du poisson; D_2 est petit, donc, D_1 est plus grand que D_2.

Comme nous le faisons en nous-mêmes, on peut distinguer ici également deux sortes d'excitation psychologique: l'une causée par la température, l'autre causée par la souffrance (nous l'appelons confusion). Pourtant on voit que le comportment du poisson est presque même dans ces deux circonstances. C'est seulement par les valeurs de D_1 et de D_2 que l'on peut les distinguer. Pour approcher de la lumière, le *Girel a punctata* (T→6) et le *Mugil cephalus* (T→0) montrent deux tendances différentes. Je pense que l'expression quantitative de ces phénomènes psychologiques d'après les valeurs des trois chiffres sont possible. Et j'aborderai cette question dans mes recherches futures.

A la fin il faut remarquer que les valeurs de ces trois chiffres varient considérablement selon les conditions expérimentales. On doit donc se garder de se servir sans réserve des valeurs absolues. Je crois pourtant qu'il est possible d'inférer l'état psychologique du poisson si l'on se réfère aux valeurs relatives des chiffres

Résumé

1. Pour les recherches de la phototaxie du poissons, nous avons proposé la méthode de déterminer la Fréquence totale de visitation (T), la Fréquence de visitation (F) et le Nombre des couleurs visitées (C).

2. En nous basant sur ces trois valeurs et sur leurs relations mutuelles, nous avons discuté les comportements des *Girella punctata* et des *Mugil cephalus* sous les conditions normales, à la haute température, dans l'alcool, aux degrés anormaux de pH.

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INFLUENCE OF VARIOUS LIGHT CONDITIONS ON THE GATHERING RATES OF FISH*

(*With 10 Text-figures and 6 Tables*)

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Preface

The influence of various lighting conditions on the gathering rates of fish has been investigated as a fundamental study on phototaxis in fish.

The authors wish to express thanks to the authorities of the Education Ministry for granting aid for Developmental Scientific Research, and also express sincere thanks to Prof. Dr. YAICHIRO OKADA, Dean of the Faculty of Fisheries, Prefectural University of Mie and to Dr. KIYOMATSU MATSUBARA, Professor of the Kyoto University who encouraged them throughout the experiment.

Experimental methods and materials employed

A wooden tank painted inside with lusterless black paint was used as part of the experimental apparatus (cf. Fig. 1). The sea water, introduced in the tank was 15 cm. in depth. A cylinder was attached to a light bulb in such a way that the bulb threw light on the surface of the water within a round area of 15 cm. in diameter. A small white bulb of 4—7 v and a bulb for the head light of a motor-car were used. Electricity was transformed from 100 v to 5—10 v for the light bulbs used in this experiment. The water temperature and the illumination were recorded before and after each experiment.

The illumination was measured with a SELEN luxmeter. All experiments were carried out in a dark room in daytime.

Materials used were captured in the sea near the Institute at Shimoda, Izu Penninsula, Sagami Bay. The test fish were reared for 2—5 days in a tank in the laboratory before they were used for the experiment. This was

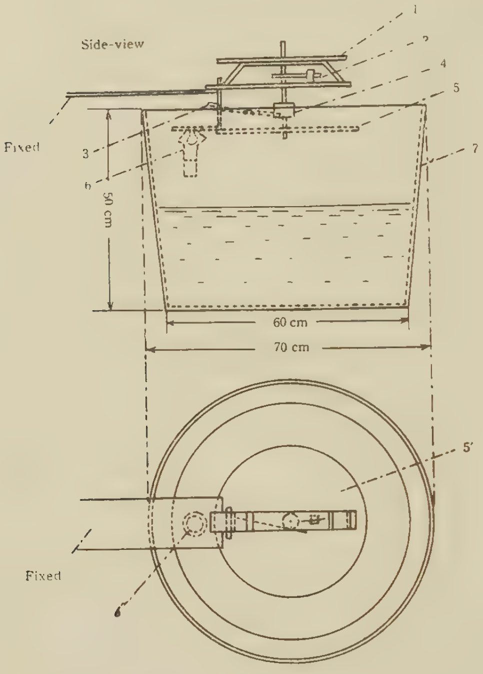

Fig. 1. Apparatus
1. Wheel 2. Metal (+) 3. Metal (—) 4. Metal ring
5, 5′ Rotary plate 6, 6′ Light bulb. 7. Water-tank

done so that all fish would be in the same condition at the time of the experiment.

Table 1. Name of the fishes and body length

Name	Body length (cm.)
Girella punctata Gray	2–2.5
Scomberomorus niphonius (C. et V.)	2–3
Oplegnathus fasciatus (T. et S.)	2–4
Monacanthus cirrhifer T. et S.	1–1.5
Safole taenura (C. et V.)	2–3
Anguilla japonica t. et S.	5–7

Results of Experiments

1) *The influence of repeated experiments on the aggregatiou of fish.*

According to PIPER (1903) and NAGEL (1911), it takes 40 minutes for the

human eye to adapt itself to darkness. However, from the results of our many experiments, it was found that thirty minutes adaptation was enough for fish, then thirty minutes were allowed in each experiment for the fish to become adapted to the darkness. Because this experiment was intended to determine the effect of successively repeated tests with the fish first completely adapted to darkness, the test was conducted continuously for ten minutes and then the light was switched off. After a ten minute interval of darkness, the light was turned on again and the test was resumed.

Thus the influence of a preceding experiment on the succeeding one was observed.

The three tests with ten minute intervals between them, as explained above, formed a series of tests which were named Test 1, Test 2 and Test 3. This series of tests was conducted five times. In this experiment, *Girella punctata* GRAY was employed. In calculating the values of the measurements of each test, the average of the number of fish counted at the end of the 10 sec., 20 sec., 30 sec., 40 sec. and 50 sec. periods was taken as the average of 30 sec., and the average of 40 sec., 50 sec., 1 min., 1 min. 10 sec. and 1 min. 20 sec. was deemed the average for 1 min., etc. In this way the average number of fish that gathered under the light during each 40 min. test was reckoned. The percentage of the fish present under the light during each period was then calculated on the basis of the total number of fish in the tank, and was regarded as the fish gathering rate for each period of time. (cf. Table 2 and Figure 2).

Judging from Figure 2, it took eight, five and four minutes for the fish to show the largest aggregation in Test 1, Test 2 and Test 3 respectively. Therefore, it is clear that less time was required during the Test 2 and the Test 3. This is probably due to the influence of the preceding test. In an experiment with young larvae of *Scomberomorus niphonius*, when the test was made 30 minutes interval of darkness between each of the test, almost no influence of a foregoing test was seen as is shown in Table 3 and Figure 3.

2) *The difference of fish gathering rate of various species of fish*

This experiment was intended to make clear the differences of the gathering rates toward a stationary light of different species of fish. In this case the area in which the fish gather were divided into two. One was a bright area (area A) which was 15 cm. in diameter at the surface of the water and the other was a dim area (area B) in which a luxmeter is not available, but the number of the fishes could be counted through the eyes of the observer with difficulty. As test fish, young specimens of *Scomberomorus niphonius* (C. et S.), *Oplegnathus faciatus* (T. et S.), *Monocanthus cirrhifer* (T. et S.) and *Anguilla japonica* T. et S. were employed. Four to six fish were

Table 2. The influence of the repeated experiments on the fish conducts. (*Girella punctata*)
Water temperature 25°–27.2° C, 30 lux

	Time	10″	20	30	40	50	1′	10	20	30	40	50	2′	10	20	30	40	50	3′	10	20	30	40	50	4′	10	20	30	40	50	5′
Test 1	Total number	5	12	8	6	11	5	8	8	9	6	9	5	10	9	9	7	10	10	7	8	9	9	12	10	8	8	11	11	8	6
	Aver. of 40 sec.			8.4			7.8			9.0			7.8			9.0			8.4			9.0			9.4			9.2			8.2
	% to no. used			42.			39.			40.			39.			45.			42.			45.			47.			46.			41.
Test 2	Total number	6	9	7	12	12	14	10	10	9	8	8	13	11	12	14	10	14	15	14	11	10	13	11	13	14	13	17	16	16	14
	Avec. of 40 sec.			9.2			11.6			9.0			10.4			12.2			12.6			11 8			12.8			15.2			15.4
	% to no used			46.			58.			45.			52.			61.			63.			59.			64.			76.			77
Test 3	Total number	8	10	9	12	11	10	9	9	10	10	11	11	12	13	8	10	10	9	13	15	12	15	14	17	17	18	16	15	15	14
	Aver. of 40 sec.			10.0			10.2			9.8			11.4			10.6			11.0			13.8			16.1			16.2			14.5
	% to no. used			50.			51.			49.			57.			53.			55.			69.			81.			81.			73.

	Time	10	20	30	40	50	6′	10	20	30	40	50	7′	10	20	30	40	50	8′	10	20	30	40	50	9′	10	20	30	40	50
Test 1	Total number	7	9	11	12	13	14	14	15	14	19	18	15	16	18	18	16	17	18	18	19	19	19	17	19	17	19	19	18	19
	Aver. of 40 sec.			10.4			13.8			16.0			17.2			17.0			17.6			18.4			18.2			18.4		
	% to no. used			52.			69.			80.			86.			85.			88.			92.			91.			92.		
Test 2	Total number	16	14	14	14	171	6	16	13	14	14	16	41	14	14	12	14	14	16	16	15	17	16	16	17	15	16	15	18	16
	Aver. of 40 sec.			15.0			14.6			14.2			14.4			13.6			15.0			16.0			16.0			16.0		
	% to no. used			75.			73.			71.			72.			68.			75.			80.			80.			80.		
Test 3	Total number	13	16	15	17	14	11	15	17	16	16	18	17	14	17	16	15	18	15	17	17	19	19	19	18	18	17	18	19	20
	Aver. of 40 sec.			15.0			14.8			16.4			16.4			16.0			16.4			18.2			18.2			18.4		
	% to no. used			75.			74.			82.			82.			80.			82.			81.			91.			92.		

Table 3. The influence of thirty minute's interval in the experiments on the fish gathering rates (*Scombermorus* sp.)
Wat. temp. 19°C, 85 lux

Time	Gathering rates %	
	I Exp.	II Exp.
30 sec.	12.5	10.0
1 min.	12.5	10.0
„ 30 sec.	22.5	5.0
2 min.	32.5	15.0
„ 30 sec.	45.0	32.5
3 min.	55.0	42.0
„ 30 sec.	57.5	45.0
4 min.	52.5	50.0
„ 30 sec.	57.5	62.5
5 min.	52.5	67.5
„ 30 sec.	47.5	70.0
6 min.	60.0	72.5
„ 30 sec.	80.0	70.0
7 min.	72.5	80.0
„ 30 sec.	72.5	85.0
8 min.	90.0	75.0
„ 30 sec.	85.5	85.0
9 min.	82.5	85.0
„ 30 sec.	81.2	80.0
10 min.	—	—
„ 30 sec.	—	—

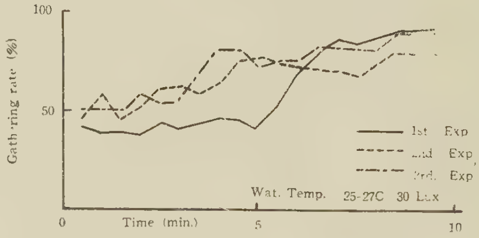

Fig. 2. Showing the influence of repeated experiment on the fish gathering rates (*Girella sp.*)

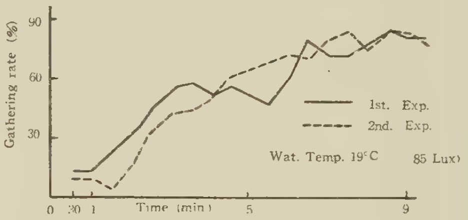

Fig. 3. Showing the influence of repeated experiment with thirty minute's intervals on the fish gathering rates (*Scomberomorus*)

used at one time and five tests were conducted for each species. As in Experiment 1, the duration of 30 minutes was reserved for darkness-adaptation before each test. The method of recording the results and culculating the average for each 30 seconds was the same as in Experiment 1. The results is shown in Table 4 and further explained in Figures 4, 5, 6 and 7. As is seen in Figure 6, *Monacanthus cirrhifer* gathered in the B area more than in the A area. But after a certain duration the value of (A+B) reached a definite value as was seen in Experiment 1.

According to Figure 4 and Figure 5 the number of *Scomberomorus* and *Oplegnathus* increased in the A area and decreased in the B area as time went on. In other words, those fish at first gathered in the B area and then shifted to the A area. This tendency was especially remarkable in *Scomberomorus*. Study of the values of (A+B) will show that they did reach the highest rate of the fish gathering after a certain duration, as was seen in the case of *Monocanthus*. *Anguilla* (cf. Figure 7) was entirely different from

Table 4. The changes of fish gathering rates in process of time in four species of fishes

Time	Fish gathering rate (%)									
	Scombcromorus Wat. Temp. 19°C 85 lux			*Oplegnathus* Wat. temp. 20° 85 lux			*Monacanthus* Wat. temp. 24° 85 lux			*Anguilla* Wat. temp. 19° 85 lux
	A area	B area	Total	A area	B area	Total	A area	B area	Total	Total area
30 sec.	17	41	58	11	18	29	9	38	43	43
1 min.	23	35	58	18	23	41	20	45	65	64
„ 30 sec.	17	48	65	24	17	41	19	49	68	40
2 min.	24	55	79	32	21	53	25	61	86	33
„ 30 sec.	37	44	81	41	27	68	24	57	82	32
3 min.	44	38	82	39	29	68	27	55	82	34
„ 30 sec.	45	41	86	38	37	57	33	57	90	30
4 min.	41	46	87	38	45	83	26	65	92	35
„ 30 sec.	50	41	91	44	41	85	36	62	98	33
5 min.	55	39	94	44	38	82	37	61	98	37
„ 30 sec.	55	39	94	40	39	79	33	65	98	38
6 min.	57	36	93	38	36	74	34	62	97	31
„ 30 sec.	69	29	95	41	35	77	34	64	98	37
7 min.	70	25	95	42	37	79	33	67	95	33
„ 30 sec.	73	19	92	43	39	82	40	59	99	25
8 min.	75	19	94	44	45	89	34	66	100	32
„ 30 sec.	79	15	94	49	41	90	33	66	100	41
9 min.	81	14	95	55	37	92	37	61	98	37
„ 30 sec.	74	16	90	55	33	88	39	60	99	40
10 min.	80	16	96	56	34	90	—	—	—	—
„ 30 sec.	84	14	98	57	38	94	—	—	—	—
11 min.	74	21	95	57	34	91	—	—	—	—
12 min.	78	16	94	—	—	—	—	—	—	—
„ 30 sec.	83	13	96	—	—	—	—	—	—	—
„ 30 sec.	78	20	98	—	—	—	—	—	—	—

the above fishes, though they swarmed at once at the time of lighting, they soon dispersed and after that showed a very stable state which was proved by the low and changeless fish gathering rate. This fact corresponds to the results of the experiment made by KAWAMOTO and TAKEDA (1950).

3) *The change of the fish gathering rate caused by a moving light*

This experiment was conducted to observe how the fish which gathered under the stationary light would change when the light was moved. Five or six of test fish were set free in the tank. After 30 minutes of darkness-adap-

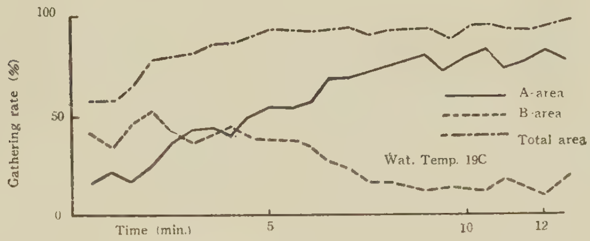

Fig. 4. Showing the timely difference on the fish gathering rate (*Scomberomorus sp.*)

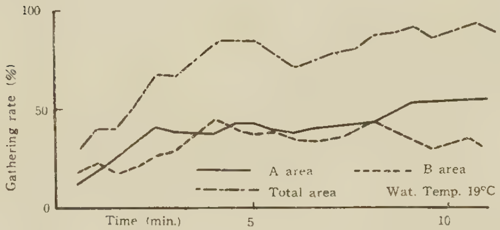

Fig. 5 Showing the timely difference on the fish gathering rate (*Oplegnathus sp.*)

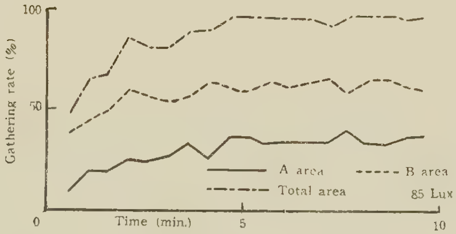

Fig. 6 Showing the timely difference on the fish gathering rate (*Monacanthus sp.*)

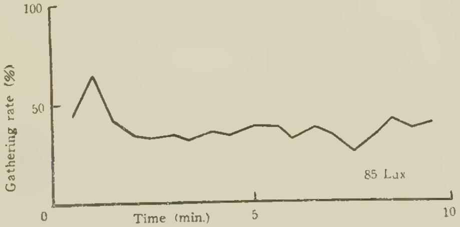

Fig. 7 Showing the timely difference on the fish gathering rate (*Anguilla sp.*)

tation the light was switched on, and 10 minutes later, the light was started moving. The speed of movement was about 5.4 cm. per sec. The light was moved counter-clockwise. As in Experiment 1, the fish gathering area was divided into the A and B areas and the average of each 30 seconds was calculated for each 10 min. period which started when the light began moving. The results of this experiment are snown in Table 5 and Figures 8 and 9.

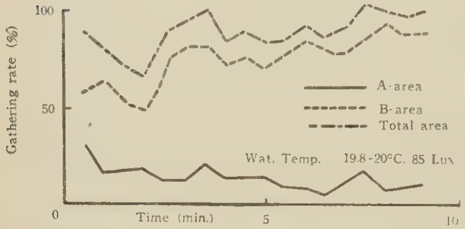

Fig. 8. Showing the changes of fish gathering rates caused by the moving of the light (*Scomberomorus sp.*)

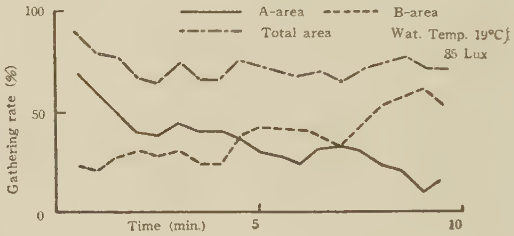

Fig. 9. Showing the changes of the fish gathering rates caused by the moving of the light (*Oplegnathus sp.*)

Reading through these results, it will be noticed that when the light was moved, the number of the fishes in the A area decreased and that in the B area increased. Therefore, in the area (A+B),……the area in which man's eye can see, the fish gathering rate did not change except for a decrease for a short while at the time of the light started to move.

It was noticed that the fish showed a little surprise at the moving light of such speed, but soon they began to pursuer after the light witnout any anxiety. The fish tended to shift from the A area to the B area. The fish tended to shift from the A area to the B area. This is considered to be effected by the moving of the light.

4) *The change of the fish gathering rates under monochromatic light*

This experiment was intended to find out how the fish came together toward the lights of different wave lenghts. Because it was difficult under the monochromatic light to observe the number of fish in the black painted tank, white enameled tank was employed. This tank was 50 cm. in diameter and 60 cm. in depth. As a light, a bulb (6 v, 50 cp) for a head light of a car

Table 5 The changes of the fish gathering rates caused by the moving of the light (*Scomberomorus* and *Oplegnathus*)

Time	Fish gathering rate (%)					
	Scomberomorus Wat. temp. 19°C 85 lux			*Oplegnathus* Wat. temp. 20°C 85 lux		
	area A	area B	Total	area A	area B	Total
30 sec.	68	22	90	30	57	87
1 min.	59	20	80	16	63	79
„ 30 sec.	43	27	78	17	53	71
2 min.	38	30	68	17	48	65
„ 30 sec.	37	28	65	12	73	84
3 min.	43	30	73	12	80	92
„ 30 sec.	40	25	65	19	80	99
4 min.	40	25	65	12	80	83
„ 30 sec.	37	38	75	13	71	88
5 min.	40	43	73	13	75	83
„ 30 sec.	28	42	70	8	69	84
6 min.	25	41	67	8	76	90
„ 30 sec.	32	83	70	5	82	34
7 min.	33	32	65	12	77	89
„ 30 sec.	30	42	72	16	84	100
8 min.	23	52	75	7	90	97
„ 30 sec.	20	57	77	9	58	94
9 min.	10	62	72	10	87	97
„ 30 sec.	17	55	72	—	—	—

was used. The monochromatic filter was attached to the top of the cylinder. In this case, the light was adjusted so that the illumination on the surface of the water was made 50 lux.

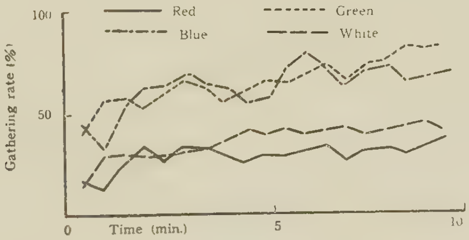

Fig. 10 Showing the changes of the fish gathering rates against monochlomatic light (*Safole taenura*)

The filters which were used in this experiment were same ones that KAWAMOTO and TAKEDA (1950) employed in their experiment. Six young fish of *Safola taenurea* were used for the test. As in the preceding experiment, after 30 min. for adaptation to darkness, the light was turned on, and the number of the fish which came together in the bright area under the light

Table 6 The change of the fish gathering rates against the monochlomatrc light (*Safole taenura*)

Time		Fish gathering rate (%)			
		red	green	blue	white
	30 sec.	17	42	47	14
1 min.		13	57	35	29
,,	30 sec.	24	58	55	29
2 min.		34	52	64	28
,,	30 sec.	27	58	65	28
3 min.		33	66	71	31
,,	30 sec.	33	63	65	32
4 min.		29	56	63	36
,,	30 sec.	25	61	56	42
5 min.		29	66	58	40
,,	30 sec.	29	65	73	43
6 min.		31	69	81	41
,,	30 sec.	33	75	73	42
7 min.		26	66	64	43
,,	30 sec.	32	74	72	40
8 min.		33	76	75	43
,,	30 sec.	30	84	67	46
9 min.		34	82	69	46
,,	30 sec	38	84	70	42

was recorded. The values from three tests were used in the calculation. In this way the experiment was conducted for each light for the four colors: red, green, blue and white. The results are indicated in Figure 10.

Figure 10 shows that the fish gathering rates are gratest for green and blue, and smallest for red. This agrees with the results of experiment made by KAWAMOTO and TAKEDA (1950).

Consideration

In experiment 1, it took eight, five and four minutes for the fish gathering rates to each their maximum values in Test 1, 2 and 3 respectively, showing

that the fish gathered more quickly after the first test. Among the possible factors which contributed to the forming of the maximum fish-gathering rate, such as the wave-length of the light, the water temperature, pH and others, the psychlogical reflection of the test fish to these factors seems to play the most important role and the variety of the time taken to reach maximum seemingly indicates that the intervals of ten minutes makes a preceding test influence on the following test. In other words, the fish make 'study'. In the experiment 2, by using four species of the fishes, such as *Scomberomorus*, *Monocanthus*, *Oplegnathus* and *Anguilla*, which do not study, the change of the fish gathering rate over a period of time was observed in the A area and the B area. It is now clear that each of the four species is distinctly different in its process of gathering.

This significantly tells the different habits of these fishes. In the above three species except *Anguilla* (this fish has a special habit), though the fish gathering rate of the A area and the B area was different, the same of these in the two area larger in each experiment until it reached the maximum. After they hit the peak, they continued at the maximum values. Moreover, according to KAWAMOTO, OZAKI and TAKEDA (1950), the change of gathering with the elapse of time shows a rather declining tendency, for the white light. Therefore, fhe gathering of fish toward light was found to be entirely different according to the species. In particular, some fish like *Scomberomorus, Oplegnathus* tended to move from the B area to the A area and others like *Monocanthus* was inclined to remain in the B area, ... in other words, they disliked the brighter area. The particular tendency of gathering in *Anguilla* had already been pointed out by KAWAMOTO and TAKEDA. The fact that the fish-gathering rate of *Anguilla* hit the peak very soon after the light was turned on and then decreased and become stable after a few minute agree with the research on *Misgurnus* conducted by HONJO and ASANO (1948).

This seems to pose a very interesting ecological problem with respect to the habits of *Anguilla* and *Misgurnus*.

In experiment 3, the moving of the light was started after the fish reached the normal condition with the light switched on. The temporary decrease of the fish gathering immediately after the starting of the light was probably due to the psychological effect on the fish.

The shift from the A area to the B area after the light began to move was probably because the fish could not follow the areas. Accordingly, it was useless to make a sharp distinction between the A area and the B area in this experiment.

In this experiment it was also observed that the fish pursued after the light with their bodies placed in the dark area and their heads pointing

toward the light. This state is probably in accord with the result of the experiment of rheotropism by LYON ('04) that a fish moves in such a way that it will keep a definite image of the outside at a certain point of its view.

In Experiment 4, the change of fish gathering rate with the lapse of time for lights of the different wave lengths was recorded. The results of this experiment completely agree with those of the experiment by KAWAMOTO and TAKEDA, that the green and blue retain the largest fish gathering rate. The rate was greater according to the order of white, green and blue, and the process of the gathering grew large likewise. As the fish gathering rates for each wave length was minutely explained in the report of KAWAMOTO and TAKEDA (1950), the authors will ommit it here.

Summary

1) In the experiments with young *Girella punctata*, which was repeatedly made at the intervals of ten minutes, it was made clear that the influence of a preceding experiment was held over to the succeeding one. In the experiment of the young *Scomberomorus niphonius* made at intervals of 30 minutes, however, no such influence was seen.

2) In the experiment with young *Scomberomorus*, *Oplegnathus* and *Monacanthus*, the fish gathering rates under the stationary light attained maximum in a definite time, and then became stabilized at this maximum value.

3) The young *Monacanthus* had a tendency of gathering in the area of the dim light first and then moving into the bright area under the bulb.

4) It was found that the *Anguilla* had negative phototaxis.

5) Fishes followed the moving light by turning their head toward the bulb and keeping their bodies in the dim area.

6) The fish gathering rates of *Safole* were also maximum in the blue and green lights as was seen on other fishes.

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Vol. 1, No. 2, November 30, 1952.

ON THE RELATION BETWEEN LIGHT GRADIENT AND FISH BEHAVIOR

(*With 13 Tables and 12 Text-figures*)

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Introduction

Many studies concerning the influence of light on the conducts of fish have been done, however, there is no work on the relation between light gradient and fish behavior except KAWAMOTO, OZAKI and TAKEDA's experiment (1950). On this subject, we have studied more precisely to establish effective foundations of the theory of fish gathering lamp at the Ichthyological Research Institute.

Materials and Methods

Young marine fish used in the experiments were taken along the coast near the Institute (c.f. Table I.).

Table 1. Fishes used in the experiments.

Names	Body length
Sphaeroides rubripes (T. & S.)	2,0 cm±0,2 cm
Mugil cephalus (L.)	3,5 cm±0,2 cm

Before the experiments, the fish were kept in aquariums of sea water in the laboratory.

A lusterless, black wooden tank which was 3 m. in length, 24 cm. in height and width, was used for the experiments conducted in a dark room. (cf. Figure 1). There was a light chamber in one end of the tank separated from the water by a pane of glass. The tank was divided into six equal sections by marking with fine short white lines on the long lateral side of the

tank, and the sections were numbered I, II, III, IV, V, and VI from the light chamber end to the far end; each section was 50 cm. long (Fig. 1).

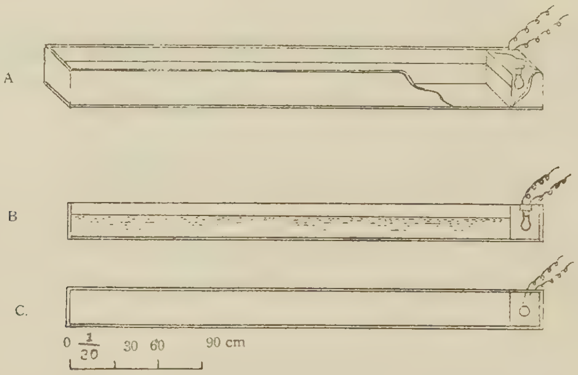


Fig. 1. A··Apparatus, B···Side view, C···Plane figure

The depth of the sea water in the tank was always 15 cm.. The upper part of the glass pane above the water surface was painted black, and the top of the chamber was covered with a black wooden lid to prevent reflection from stray light leakage. Only the light from the chamber penetrated the sea water through the glass pane. Light bulbs of 2 cp. 10W, 20W, 100W and 200W of 100 volts a.c. were used as the sources of light. In each experiment ten fish were transferred to the experiment tank, after allowing the fish to become adapted to the darkness for thirty minutes, the light was turned on, and the number of fish in each section was counted every thirty seconds for fifteen minutes, and the fish gathering rates were calculated by averaging those numbers.

A different group of test fish was used for each experiment to avoid schooling, and the experiments were carried out both in the daytime and at night to see if any differences might be found in the gathering rates.

Preliminary Consideration

Distribution of intensities of the light in the water.

The relation between the distance from the source of the light and intensity of the light are shown in Table 2 and Figure 2.

From Figure 2, it was considered that the gradient of the light intensities through water in the tank is expressed by Lambert's formula $I=I_0 e^{-\alpha x}$ and from this equation the values of I_0 and α were claculated in accordance with each value of light wattage by the method of the least square from the numbers determined (Table 3).

Table 2. On the relations between radiant intensities* and distances from the source of the light.*

Light bulbs used.	Distance cm. 5	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	
2 cp.	32	26	10	5															Lux
10 W		108	46	20	15	8	6												Lux
20 W		170	83	49	30	20	13	7											Lux
40 W				280	180	118	73	50	33	23	15	10							Lux
100 W					482	353	245	180	128	93	68	46	30	23	19	14	10		Lux
200 W						482	340	245	185	139	98	73	52	32	37	23	16	12	Lux

* intensity of the reflex light from the other end of the tank was negligible.

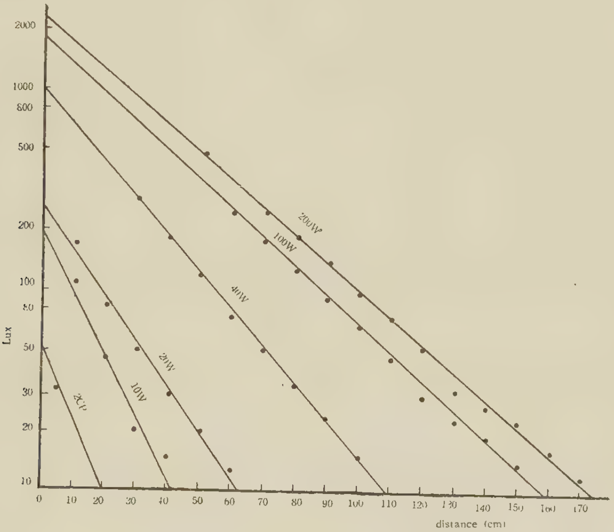


Fig. 2. Showing the relation between light intensities and distances from the source of the light.

Table 3. The values of I_0 and α, calculated from numbers determined.

200 W	$I = 2224\ e^{-0.0313\ x}$
100 W	$I = 1783\ e^{-0.0330\ x}$
40 W	$I = 1001\ e^{-0.0429\ x}$
20 W	$I = 258.6 e^{-0.0529\ x}$
10 W	$I = 194.6 e^{-0.0587\ x}$
2 cp.	$I = 52.6\ e^{-0.0726\ x}$

The average intensity of the light in each section was calculated from the values in Table 3. For instance, the average intensity in a certain section is shown as follows, if the distance of a certain section from the light source is expressed as $\bar{I}x \sim x+50$ cm. Then the value of the average intensity in each sections is shown: $\bar{I}x \sim x+50 = 1/50 \int_{x}^{x+50} I_0 e^{-\alpha x} dx$

Therefore, the intensity of light in each section for each size bulb is shown in Table 4.

Table 4. Average radiant intensities in each sections against every light bulbs.

Light bulb used	Section I	II	III	IV	V	VI	
2 cp.	14.11	0.374	0.0099	0.0026	—	—	Lux
10 W	54.83	1.767	0.057	0.0018	0.00006	—	Lux
20 W	87.33	6.2	0.44	0.0313	0.002	0.00015	Lux
40 W	402.04	47.06	5.510	0.645	0.075	0.0082	Lux
100 W	873.09	167.67	32.20	6.18	1.19	0.23	Lux
200 W	1123.96	235 0	49.13	10.27	2.12	0.44	Lux

Experiments

The fish gathering rates obtained by experiments conducted both in the daytime and at night are shown in Table 5 (A) and (B) and Figure 3 (A) and (B).

From the Table 5 (A) and (B), we can explain various matters as follows:

(1) On the distribution of fish in each section of the experimental tank for various light bulbs

In Figure 3, differences in the distribution of the fish in the tank are apparent in both *Sphaeroides* and *Mugil* when the gathering rates of the fish for various lights in the daytime experiments is compared with the gathering rates for the night-time experiments using the same lights. Moreover, it is possible to distinguish differences in the distribution curves of the fish between day and night experiments, even in the same intensity of light. Judging from the distribution data of the fish under various light intensities, the authors classified the distribution curves as indicating three different forms of phototaxis as follows:

Table 5. Sectional distributions of fishes at the experiments in the day and in the night.

(A) *Sphaeroides rubripes* (T. et S.)

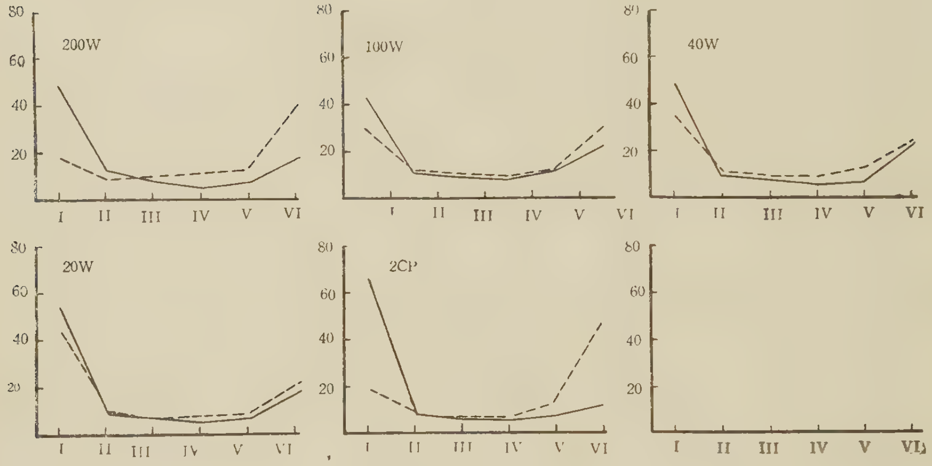
		Section					
		I	II	III	IV	V	VI
Day	200 W	49.3	13.1	8.1	5.7	7.3	16.5
	100 W	42.4	10.7	8.6	7.0	10.2	21.1
	40 W	48.4	9.0	7.8	5.7	7.0	22.1
	20 W	55.0	9.2	6.3	5.3	6.6	17.6
	2 cp.	64.8	8.1	5.1	4.4	6.2	11.4
Night	200 W	18.3	8.8	9.3	10.6	13.7	39.3
	100 W	28.6	11.6	10.1	9.1	11.7	28.9
	40 W	34.9	11.1	9.1	8.7	12.7	23.5
	20 W	44.3	10.1	6.6	7.7	9.4	21.9
	2 cp.	19.0	7.2	6.2	6.2	13.0	48.4

Gathering rates (%)

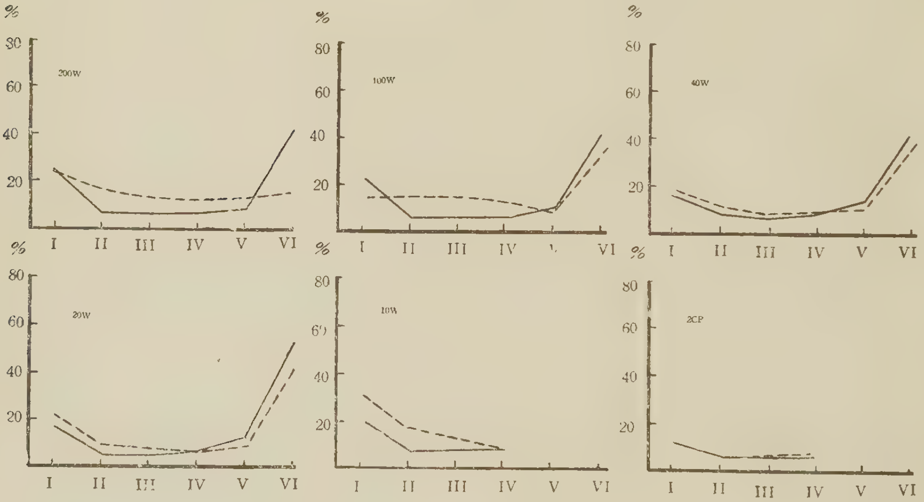
(B) *Mugil cephalus* L.

		Section					
		I	II	III	IV	V	VI
Day	200 W	26.1	8.0	7.1	7.5	9.4	41.8
	100 W	23.6	7.2	7.0	7.4	11.8	43.0
	40 W	17.0	9.1	6.8	8.9	14.5	43.8
	20 W	17.8	6.0	5.6	7.8	12.5	50.3
	10 W	20.5	7.8	7.7	8.5	55.5	—
	2 cp.	13.4	7.6	6.2	6.6	66.2	—
Night	200 W	24.9	16.9	14.0	13.7	14.0	16.5
	100 W	14.7	14.4	15.0	12.1	8.9	34.9
	40 W	19.4	12.6	9.4	10.0	12.2	36.4
	20 W	23.4	10.0	8.2	7.2	9.4	41.8
	10 W	31.6	16.4	12.9	8.6	—	—
	2 cp.	13.6	6.6	7.7	8.4	—	—

Gathering rate (%)



(A) Sphaeroides rubripes (T. et S.)



(B) Mugil cephalus Linne

Fig. 3. (A) and (B) Showing the distribution rates of fishes in every sections in the tank caused by the various intensities of light in the day or in the night experiments.

full line·········the day experiment

dotted line ···the night experiment

1. Positive light seeking behavior ..... when the fish increased in number in sections I and II and decreased in sections V and VI.
2. Negative light seeking behavior ..... when the fish increased in number in sections V and VI, and decreased in sections I and II.

3. Confused behavior ..... when the number of fish increased in number in the middle part of the tank, such as in sections III and IV, and decreased at both ends, in sections I, II, V, and VI.

When the number of fish distributed in each section for the various light intensities is compared with the gathering rates under the 2 cp. light as a standard, the behavior of the fish appears as shown in Table 6.

Table 6. Distribution of fish in the various light intensities
Sphaeroides (in daytime)
+ is a sign of increase — is a sign of decrease

In light compared with	Section number, increase or decrease	Behaviors
20 W............ 2 cp	—I, +IV, V, VI	Negative l.s.b.
40 W............ 20 W	—I, Transfer to opposite end	,,
100 W............ 40 W	—I, VI. +II, III, IV, V.	Confused b.
200 W............100 W	+I, II, III. —IV, V, VI.	positive l. s. b.
(in night-time)		
20 W............ 2 cp	+I, II. —V, VI.	Positive l. s.b.
40 W............ 20 W	—I, +V, VI	Negative l.s.b.
100 W............ 40 W	—I, II +VI	,,
200 W............100 W	—I, II +IV, V, VI	,,

Mugil (in daytime)

In light compared with	Section number, increase or decrease	Behavior
10 W............ 2 cp	+I, II, III. —V, VI	Positive l. s.b.
20 W............ 10 W	—I, II, III. +V, VI	Negative l.s.b.
40 W............ 20 W	—I, VI. +II, III, IV, V.	Confused b.
100 W............ 40 W	+I, II, III. —IV, V, VI.	,,
200 W............100 W	+I, II. —III, IV, V, VI.	,,
(in night-time)		
10 W............ 2 cp	+I, II, III. —V, VI	Positive l. s.b.
20 W............ 10 W	—I, II III. +V, VI	Negative l.s.b.
40 W............ 20 W	—I, VI. +II; III, IV, V.	Confused b.
100 W............ 40 W	—I. +II, III, VI	,,
200 W............100 W	+I, II. Uniformly in other sections	,,

The results of this experiment show generally that a higher or lower intensities than a certain standard light the gathering tendencies of *Sphaeroides*

and *Mugil* become negative in proportion to the distance from the source of light. Therefore, it is easily supposed that fishes will become the more negative to the light, the greater the intensity, if the tank is long enough.

In these experiments, the length of the tank is definite, and the condition of the low gathering rate in sections I and VI, while a high rate is observed in the middle sections at the time when the light gains in intensity, shall be considered to indicate an excess of light. In the daytime, confused behavior appeared under a light intensity of 100W for *Sphaeroides* and 40W for *Mugil*, while in the night-time, the fish transferred regularly to the end opposite from the light for light intensities up to the 200W, while *Mugil* showed confused behavior at 40W as in the daytime. The point where confused behavior appears is different in different species of fish, and it also appears there are different optimum light intensities respectively for the various species. Differences in the reaction to light are also observed between day and night experiments.

(2) On the relation between the gathering rate of fish and light gradient.

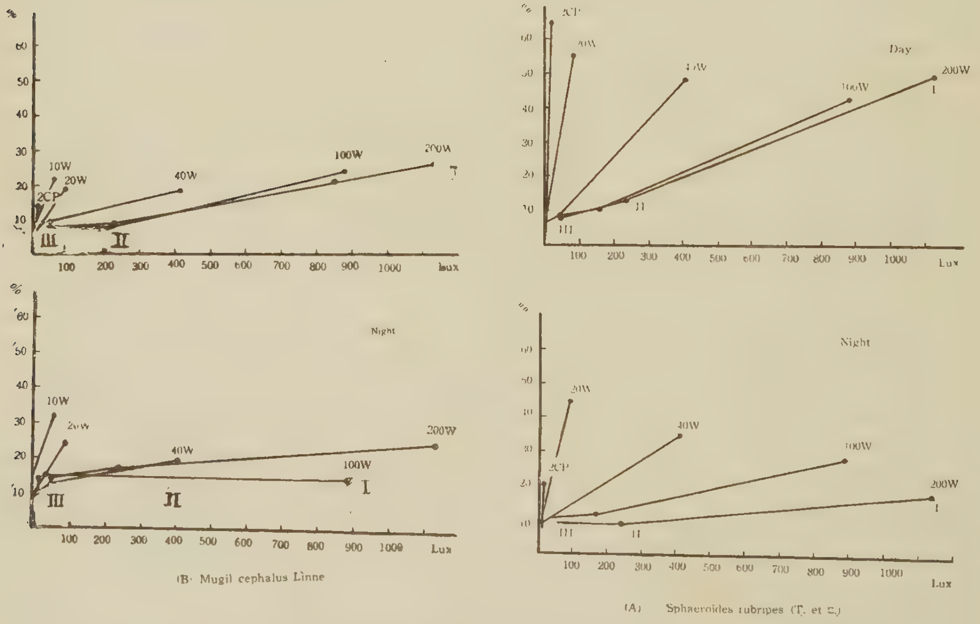


Fig. 4. (A) and (B) Showing the relations between distribution rates of fishes and light intensities. (Semilogarismic graph) and I. II. III. Show the number of each section in the tank.

The relation between the gathering rate of fish and the light gradient is shown in Figure 4 (A) and (B), and the curves in the figures are almost linear

at sections I, II and III. From these results, it may be said that the gathering rates decreased in exponential function according to the distance.

The slope of those curves generally become smaller the more the intensities of the light increase, except in a few abnormal instances. Those slope are comparatively the same in both day and night, as will be seen in the figures, and the slope are related to the calculations of the gathering rates of fishes which are mentioned later.

(3) Intensity of the light and the gathering rate of fish

The relation between the value of the gathering rate in the 1st. section of the tank and the intensity of each light bulb (Watts), are shown in Figure 5 calculated for on the data in Table 5 (A) and (B).

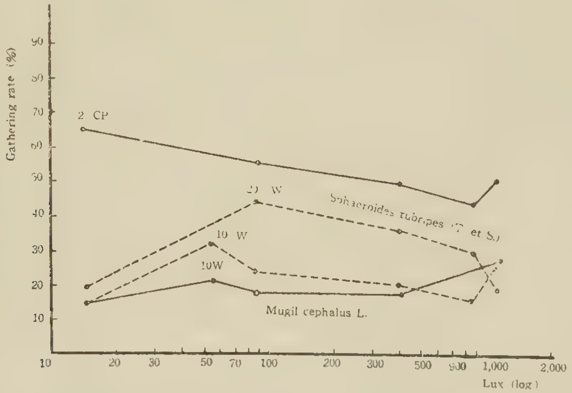


Fig. 5. Showing the relations between the fish gathering rates and light intensities at the 1st. section of the tank.
full line············the day experiment.
dotted line·········the night experiment

From Figure 5, it is found that the maximum values of the gathering rate of *Sphaeroides* exist in 2 cp. (14,11 lux) in the day and 20W (87,33 lux) in the night, while those of *Mugil* exist in 10W (54,83 lux) both in day and in night, and the gathering rates decrease, whether the light intensities become strongers or weeker, than a certain definite light value. It can be considered that the cause of decreasing in the gathering rates of fish may be caused by too much intensity or too high stimulation, and that the maximum gathering rate, will be observed when the intensity or the stimulation is optimum for the fish. Oka (1950) reported the data for intensities of the light at the maximum gathering rates of fresh water fish as shown in Table 7.

Table 7

Name of fishes	lux (at Max. gathering rates)
Aplocheilus latipes	24,5—44,5
Misgurunus anguillicandatus	44,5—60,5
Carassius auratus	30,0—60,5

Our data of intensities at the maximum gathering rates of young marine fishes are as follows:

Table 8

Name of fishes	lux (at Max. gathering rates)
Mugil cephalus (in day)	54,83
„ (in night)	„
Sphaeroidee rubripes (in day)	14,11
„ (in night)	87,33

The values in the two tables are nearly the same, although some of them are somewhat different in accordance with different species.

In comparing the gathering rates of the day and the night experiments, Figure 5 shows that the maximum gathering rate of *Sphaeroides* appeared in daytime and that of *Mugil* appeared in the night-time without any relation to the light intensity. Differences of the gathering rates between day and night experiments were observed by KONISHI, one of our investigators at the Institute, in *Girella punctata, Plotosus angui laries* and certain other species, but such facts are not yet reported in publications, and the causes of those differences are now being studied.

(4) Variation of the gathering rates of fish in proportion to time

Observations on the number of fish only in section I in the tank, were done every thirty seconds for fifteen minutes, after adaptation for thirty minutes in a dark room, and we treated the numbers of fishes at the time of 0′30″, 1′10″ and 1′30″ of observations as a datum of 1 minute and also those of 1′10″, 1′30″ and 2′0″ as 1′30″, and so on. Thus we obtained Tables 9 (A) and (B) and Figures 6 (A) and (B) as follows:

Table 9. Timely changes of fish gathering rates against every light bulbs in section I in the tank.

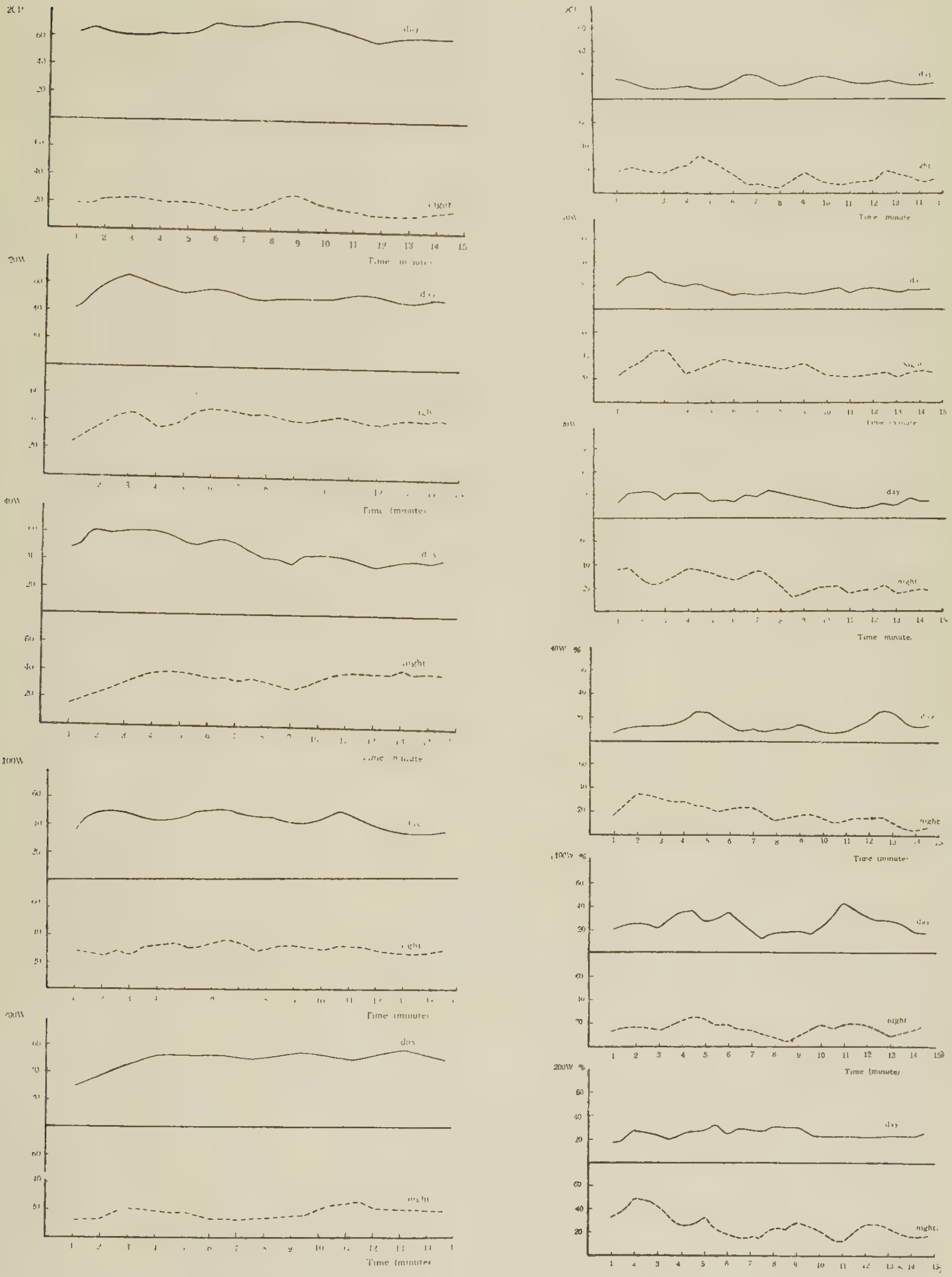
(A) *Sphaeroides rubripes* (T. et S.)

	Time (Minute)	1		2		3		4		5		6		7		8		9		10		11		12		13		14	
		Gathering rate (%)																											
Day	2 cp.	63	66	64	63	61	61	63	61	63	65	69	69	69	69	71	72	73	70	68	65	63	59	59	61	62	63	61	63
	20 W	42	49	58	63	67	64	59	57	54	54	58	56	53	50	50	51	51	51	52	51	53	54	54	51	49	49	52	51
	40 W	47	53	61	59	61	60	61	59	54	51	53	55	52	57	42	41	38	45	44	45	43	40	36	38	41	41	40	41
	100 W	33	46	49	48	46	43	41	41	45	49	49	49	46	44	44	41	39	40	45	48	45	41	37	35	34	33	35	35
	200 W	29	32	37	41	46	48	51	52	51	51	50	51	50	48	49	51	52	53	50	50	48	48	50	53	54	52	50	48
Night	2 cp.	19	19	23	23	24	22	21	21	21	19	18	16	16	17	21	26	26	22	19	17	16	13	13	12	12	14	15	15
	20 W	25	31	38	44	47	45	37	37	41	48	50	49	48	47	46	43	42	41	43	45	43	41	40	41	44	43	44	43
	40 W	15	19	21	27	31	35	33	39	38	35	35	35	32	34	37	31	27	29	33	37	39	39	39	39	42	39	40	39
	100 W	27	26	24	28	25	30	31	33	29	30	34	36	33	28	29	31	31	30	29	32	31	31	27	27	25	26	27	28
	700 W	13	13	14	20	21	21	19	18	18	15	13	13	12	13	13	15	15	16	21	23	24	25	25	21	20	21	19	19

(B) *Mugil cephalus* L.

Gathering rate (%)

	Time (Minute)	1		2		3		4		5		6		7		8		9		10		11		12		13		14	
Day	2 cp.	17	15	11	8	8	10	11	8	8	11	16	20	20	15	10	11	16	19	19	16	15	13	15	15	13	12	12	13
	10 W	21	29	29	33	25	22	20	23	19	17	13	15	13	14	15	15	14	15	15	14	15	19	20	18	16	18	18	19
	20 W	13	22	22	23	16	21	21	21	14	16	13	19	18	23	22	19	17	15	13	10	9	9	10	14	12	18	14	12
	40 W	8	11	14	13	15	15	18	26	25	19	12	8	10	7	10	10	14	11	9	7	9	15	18	27	25	16	14	15
	100 W	19	23	25	23	19	30	34	35	25	27	33	26	17	11	16	16	17	14	21	33	40	36	28	26	26	23	16	16
	200 W	18	21	28	25	23	21	25	29	29	32	26	29	28	27	32	30	31	25	23	23	23	23	22	23	23	24	23	27
Night	2 cp.	19	22	20	19	18	23	24	32	27	21	15	7	8	5	5	11	17	11	8	6	8	9	11	18	15	14	8	10
	10 W	23	31	35	45	45	37	26	29	33	39	34	35	31	31	29	31	34	29	23	23	21	23	25	26	22	26	28	25
	20 W	35	37	28	22	25	32	37	36	33	29	27	32	35	32	23	13	16	21	22	24	16	19	19	23	16	18	20	18
	40 W	17	26	34	35	32	29	29	25	25	21	24	25	24	19	13	15	18	18	15	11	13	16	15	16	11	7	5	7
	100 W	13	17	16	17	12	17	22	25	23	17	19	14	14	9	7	4	9	12	18	14	19	19	19	13	9	12	13	15
	200 W	34	39	49	49	42	33	27	28	34	23	19	16	18	16	25	23	29	26	21	15	13	21	27	27	25	20	17	17



(A) *Sphaeroides rubripes* (B) *Mugil cephalus*

Fig. 6. (A) and (B) Showing timely changes of the fish gathering rates in the 1 st. section of the tank

full line................................ the day experiment
dotted line .... the night experiment

In general, the gathering rates of fish caused by the light stimulation not only appeared in the positive but also in the negative, and sometimes the maximum value appeared soon after lighting, may be cansed by initial reflex, and others not, and the results of these experiments are explained as follows.

Sphaeroides: In the day experiments, gathering rates showed maximum at the light source of 2 cp and the variation in proportion to time was comparatively small. The fish gathered to the source of light quickly after lighting and not swim away thereafter. For such a condition, in other words, it may be said that no reflex gathering occured and attained equilibrium quickly. However, with 20W, 40W and stronger sources of light, gathering rates in section I gradually changed in proportion to time, and the rates become constant after 5-6 minutes at 20W, and 8-9 minutes at 40W and, in other words, the initial reflex gathering rates were greater in proportion to the strength of the light. The equilibrium rates of gathering appeared soon after lighting 2 cp. source of light in the night, and the rate became constant after that, but the effect of initial reflex on the rate of gathering could not be seen in spite of increasing the light from 20W to 40W. Equilibrium rates of gathering were attained in 5-6 minutes in the case of 20W and in 10-11 minutes for 40W and became constant.

The gathering rate of fish in proportion to time for the electric bulbs of 100W or 200W in daytime was almost constant and it is supposed that not only the equilibrium rate of gathering, but also the confused behavior was due to too strong light intensity.

In the night experiments with bulbs of 100W and 200W, the curves, were seen to be the same as those in day experiments, however, such conditions were different practically in spite of coinsiding superficiarlly and it is considered that the rates of equilibrium were appeared soon after lighting and the rates last thereafter.

Mugil: Although the changes of curves of *Mugil* were not as clear as were seen in the curves of *Shaeroides,* the decreasing rates of the fish gathering were also observed in *Mugil*, and the rate of decrease of the latter are larger in the night than in the day, while the rates of *Sphearoides* are much greater in day than at night. Such variations of the gathering rate of fish in proportion to time, were observed in the different species of fishes by other investigators. KOBAYASHI (1952) reported that the gathering rate became constant within 7-8 minutes after lighting and the rates changed in the different kind of light even in the same species. In the experiments of *Sphaeroides* and *Mugil*, the rates decreased according to time and remained at a certain condition for some time. Variations of the gathering rates of fish in proportion

to time with different sources of light, showed that the decreasing rates of the gathering fishes were comparatively small or sometimes no variation at all when the ight source which showed maximum values of the gathering rates were used. In other words, variation in reflex gathering rate was small and equilibrium values of gathering were high.

Consideration

(1) Mathematical considerations

In the experiments, (Fig. 3 A and B) distribution curves of the fish gathering rates in each sections (I–VI) in the tank are shown diagramatically U forms as were seen in the experiments of KAWAMOTO, OZAKI and TAKEDA (1950) and the distribution curves are shown diagramatically in Figure 7. Through these curves, the distribution of fish in the tank can be analyzed as belonging to two forms, the one shows positive gathering rates and the other is negative. Positive reaction means that the fish gathered at the end of the tank near the light (Figure 7, G), and negative reaction means that the fish gathered toward the end of the tank opposite from the light (Figure 7, F). If the length of the tank was infinite, the negative distribution of fish would extend far away from the source of light, but at any rate it is considered that some fish will react to the light even far away from the light and other fish will not react to it even when close to the light.

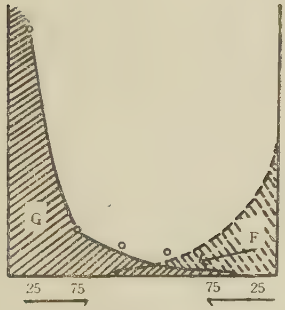


Fig. 7. Gathering rates of fish in each sections in the tank is shown diagramatically.
G…means positive reaction to the light
F…means negative reaction to the light

The relation between the light intensities and the fish gathering rates was linear from sections I to section III of the tank as was mentioned in page 159. Therefore, we can presume that the fish gathering rates decrease exponentially in proportion to the distance from the light. Then, such relation can be expressed as follows:

$$G=G_0e^{-\beta x} \quad \cdots\cdots\cdots (1)$$

When G is the gathering rate of fish at the distance x from the light and G_0 is the gathering rate at $x=0$, and β is the positive decreasing coefficient. From the same meaning, we can express the negative gathering rates of fish (Figure 7. F) by the equation:

$$F = F_0^{-\alpha x} \quad \cdots\cdots\cdots \quad (2)$$

When F means the number of fish of the negative gathering in distance x from the source of the light and F_0 is the number of the negative gathering at the distance of $x=0$ and α is the negative decreasing coefficient in this case.

There is no influence of F in sections I and II and also no influence of G in the section V and VI, and therefore, we can calculate the coefficients by the method of least square as in Table 10.

Table 10. The values of α and β, calculated from the data in the sectional distribution of *Sphaeroides rubripes* (T. et S.) at the experimntes in the day and in the night.

	Day	
200 W	$G = 95.61e^{-0.0265x}$	$F = 24.8e^{-0.0163x}$
100 W	$G = 83.0e^{-0.0272x}$	$F = 30.4e^{-0.0145x}$
40 W	$G = 111.9e^{-0.0336x}$	$F = 39.3e^{-0.0230x}$
20 W	$G = 134.7e^{-0.0358x}$	$F = 28.7e^{-0.0197x}$
2 cp.	$G = 179.8e^{-0.0421x}$	$F = 15.5e^{-0.0122x}$

	Night	
200 W	$G = 26.5e^{-0.0146x}$	$F = 66.6e^{-0.0211x}$
100 W	$G = 448e.^{-0.0180x}$	$F = 45.5e^{-0.0181x}$
40 W	$G = 62.4e^{-0.0223x}$	$F = 26.1e^{-0.0097x}$
20 W	$G = 92.3e^{-0.0295x}$	$F = 33.2e^{-0.0168x}$
2 cp.	$G = 30.9e^{-0.0194x}$	$F = 93.0e^{-0.0261x}$

To obtain the number of fish which showed positive reaction to light, G is integrated from 0 to ∞ as follows:

$$\int_0^\infty G dx = \int_0^\infty G_0 e^{-\beta x} dx = G_0/\beta$$

By the same meaning, to get the number of fish showing the negative reaction, F is integrated from 0 to ∞ as this:

$$\int_0^\infty F dx = \int_0^\infty G_0^{-\gamma x} dx$$

Then, we can calculate the total number of fishes in the tank as follows:

$$\int Gdx + \int Fdx$$

Therefore, if we express the fish gathering rate by the relative number between the fishes which showed positive gathering and those of total number, the equation is as follows:

$$\text{Fish gathering rate} = \frac{\int Gdx}{\int Gdx + \int Fdx}$$

If we calculate this equation according to the data for each light bulb, we get the data shown in table 11.

Table 11. *Sphaeroides rubripes* (T. et S.)

Day experiment

	200 W	100 W	40 W	20 W	2 c.p.
$\frac{G_0}{\beta}$	3607.8	3051.5	3330.4	3773.1	4364.1
$\frac{F_6}{\gamma}$	1521.5	2096.6	1708.7	1464.3	1267.4
$\frac{\frac{G_0}{\beta}}{\frac{G_0}{\beta}+\frac{F_0}{\gamma}}$	0.7034	0.5850	0.6609	0.7204	0.7745

Night experiment

	200 W	100 W	40 W	20 W	2 cp.
$\frac{G_0}{\beta}$	1130.1	2488.9	2798.2	3128.8	1592.78
$\frac{F_0}{\gamma}$	3109.0	2513.8	2690.7	1976.1	2262.2
$\frac{\frac{G_0}{\beta}}{\frac{G_0}{\beta}+\frac{F_0}{\gamma}}$	0.2666	0.4975	0.5098	0.6129	0.3097

In page 159 section (3), it was pointed out that the fish gathering rate almost coinsides with the data calculated by the equation above mentioned (Figure 5 and Figure 8).

In the experiments of TAKEDA (1951), KONISHI (1952) and UNO (1951) at the

Ichthyological Research Institute, the fish gathering rates have been explained by the data which were observed only in the numbers of fish gathered in the direct light fields, and in view of the above mentioned relationship, it can be concluded that the conclusions of those three investigators are correct in the limit of the relative data.

(2) On the spectral luminosity

The equation of the rate of absorption of light into water is generally expressed (LAMBERT's equation):

$$I = I_0 e^{-\alpha x} \qquad (3)$$

and that of the fish gathering rates in the water of the tank is expressed as is shown in equation (1):

$$G = G_0 e^{-\beta x}$$

and the values of absorption coefficient α in (3) and β positive decreasing coefficient in (1) do not coincide with each other.

Therefore, we can consider that the gathering rates of fish are not proportional to the values of intensities of light.

KAWAMOTO and KONISHI (1952) reported that the relative gathering rates of fish are proportional to the relative values of spectral luminosity (H), and that was as expressed in their paper as follows:

$$G_1/G_2 = H_1/H_2$$

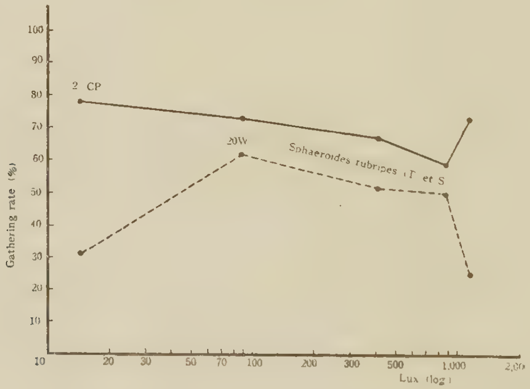


Fig. 8. Showing the fish gathering rates (%) calculated

by the equation $\dfrac{\int G dx}{\int G dx + \int F dx}$

full line············the day experiment
dotted line ······the night experiment

Then, we concluded that it was important to see the relation between

the gathering rates of fish and the average spectral luminosity in each section of the tank instead of with the intensity of the light. The spectral luminosities H are shown in the following equation from KAWAMOTO and KONISHI'S work (1952)

$$H=\int E_{\lambda}T_{\lambda}V_{\lambda}d\lambda$$

Where, E_{λ} is the intensity of light, T_{λ} is the penetrating rate of light into the sea water and V_{λ} is visibility at the wave length λ. Light energy E_{λ} against wave length λ decreases in proportion to the penetrating rate T_{λ}.

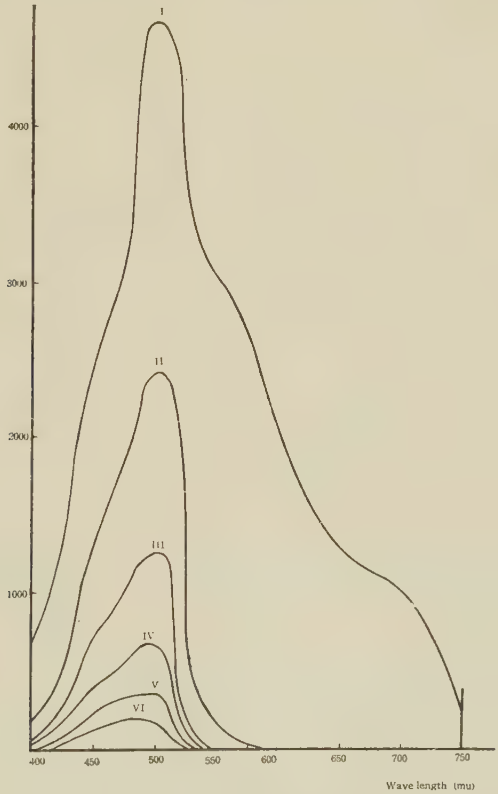


Fig. 10. Showing the average values of radiant intensities of the light against each sections of the water tank. I. II……IV are the numbers of the sections in the tank.

As the absorption coefficient α in equation (3), can be calculated from values of penetrating rate, light energy $E_{\lambda x}$ at the wave length λ which penetrates into water through a distance x is expressed from equation (3) as follows:

$$E_{\lambda x}=E\lambda e^{-\alpha x}$$

Accordingly, the values of the average energy from distance x (cm.) to $x+50$ (cm.) is

$$\bar{E}_{\lambda x-x+50}=1/50\int_{x}^{x+50}E\lambda e^{-\alpha x}dx$$

From this equation, the average value of light energy in each section for each wave length was obtained as shown in Figure 10. Spectral sensitivity of the retina is different according to the wave lengths and to the species of fish, however, (1932) H. GRUNDFEST reported the maximum value of spectral sensitivity of *Lepomis* to be 540 mμ, and von Studnitz (1940) reported in his book the values of those spectral sensitivities was 505~540 mμ in various fishes.

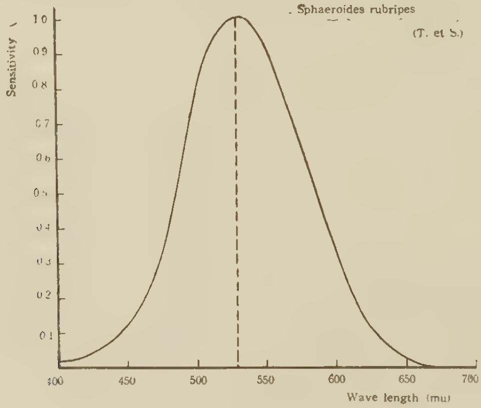


Fig. 11. Hypothesized visibility curve of *Sphaeroides rubripes*

It is said that the type of the visibility curve of *Sphaeroides* was analogous to that of man except that the maximum value of the curve was at 530 mμ according to the results of an experiment by KAWAMOTO and KONISHI (1952), and therefore the curve will be shown in Figure 11. When the values of the multiplication of average values of light energy in each section (calculated from Figure 10) by the values from the visibility curves of fish are integrated in respect to wave lengths, the values of the spectral luminosity (H) are obtained. The values, calculated from the numbers for the 40W light bulb are shown in Table 12 and Figure 12.

Table 12. Average values of the spectral luminosities of *Sphaeroides*.

Section in the tank	I	II	III	IV	V	VI
Special luminosity (H)	705	160	75	40	22	14

Fig. 12. Showing the spectral luminosities calculated from radiant intensities of the light in each sections of the water tank (*Sphaercides rubripes*)

From this table 12, it is seen that values of the spectral luminosity (H) decrease in proportion to exponential function according to distance x, therefore, the equation

$$H=H_0e^{-\delta x} \quad \cdots\cdots (4)$$

will be held. The values of δ, called luminosity coefficient, is caculated by the least squares as follows:

$$\delta \fallingdotseq 0.03$$

The values of the positive decreasing coefficient β (Table 10) and the luminosity coefficient δ of equations (1) and (4) are as follows:

$$\beta=0.0336 \qquad \delta \fallingdotseq 0.03$$

and it shall be able to admitted that the two values above mentioned are nearly the same.

If we assume that $\beta \fallingdotseq \delta$

then, that the equation $G/G_0=H/H_0$ will be considered true. and it was turned out that the result coincided with the equation $G_1/G_2=H_1/H_2$ as was shown by KAWAMOTO and KONISHI (1952).

On the relation between spectral luminosities and fish gathering rates with other light bulbs, it could not be calculaied as the radiant intensities of

them could not be obtained. But we believe that the relations are the same in those cases.

Summary

(1) The gahtering rates of *Sphaeroides* and *Mugil* show almost the same tendencies of sectional distribution as the type U in the limited length water tank used in this experiment.

(2) It is considered that the optimum light intensities were found because the fish tended to gather further away from the light when the light intensity was stronger or weaker than a certain optimum value.

(3) We found that the fish gathering rates are different in the day and in the night from the facts of the distribution of the gathering rates, and of the maximum values of the curves of the gathering rates for some light intensities.

(4) The value of the light intensity at which fish gathering rates are highest is 55 lux in *Sphaeroides*, both in the day and in the night, the values are 15 lux in the night and 87 lux in the day in *Mugil*.

(5) It is considered that the fish gathering rates can be divided into two types: equilibrium gathering rate and reflex gathering rate. The equilibrium gathering rate is almost always constant, while the reflex gathering rate appears quickly soon after lighting and gradually changes in proportion to time.

(6) It may be considered that the relative fish gathering rates coincided with the relative spectral luminosity as both the values of the positive decreasing coefficients of the equations of the fish gathering rate and the luminosity coefficient of the equation of the spectral luminosity was 0,03 each other.

In conclusion, the authors wish to express their hearty gratitude to Mr. BINZO MURAYAMA, President of the Fisheries Research Institute, who granted a subsidy from the Institute, and also to Dr. YAICHIRO OKADA, Dean of the Faculty of Fisheries, Prefectural University of Mie and Dr. K. MATSUBARA, professor of Kyoto University for their kindness throughout this experiment.

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Vol. 1, No. 2, November, 30, 1952.

AN EXPERIMENTAL STUDY ON THE EFFECT OF LEADING FISH BY FISH ATTRACTION LAMPS*

(*With 24 Tables and 13 Text figures*)

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Preface

A biological research concerning the effect of intermittent lighting on phototaxis in fish could be found nowhere at the present time, so the authors have carried out this experiment with the objective of finding the basic facts about this subject at the Ichthyological Research Institute and now wish to make a report on this matter.

Before going further, the authors wish to acknowledge their indeptness to Mr. B. MURAYAMA, President of the Fisheries Research Institute, Dr. Y. OKADA, Dean of the Faculty of Fisheries, Prefectural University of Mie, and Dr. K. MATSUBARA, Professor of Kyoto University for their kind sugestions.

Materials of Experiment

Two kinds of fish taken from near the Institute were provided for this experiment. Their names are as follows:—Young marine fish; Mejina (*Girella punctata* GRAY) and fresh water fish; Killifish (*Aplocheilus latipes* T. et S.); body length are ranged from 2 to 3 cm.

It is regretted that adult marine fish could not be provided for this experiment with the fish attraction lamps, but the difficulty of naturally keeping them in an aquarium made their use impractical. For this reason, the results gained by this experiment might be inapplicable to all kinds of fish, but it may be well allowed to compare these results with other cases.

The Mejina fish shows great difference between the degrees of phototaxis in the day time and that at night as shown in Figure 1, while the Killigsh showed no such difference between night and day as is shown in Fig. 2, so experiments of Mejina were performed in the dark room only when conducted during the day time and experiments of Killifish were carried out both in the day and in the night.

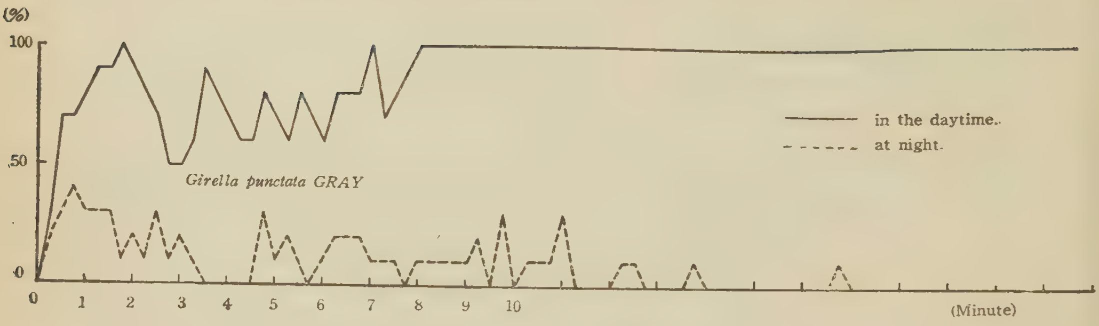


Fig. 1 Showing the difference of gathering rate between in the daytime and at night.

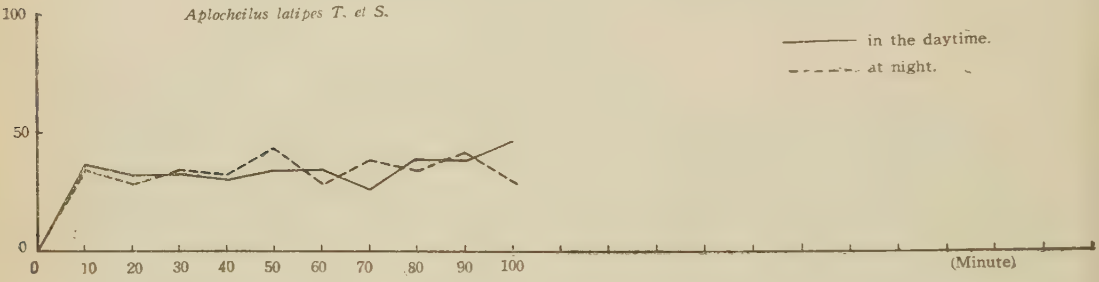


Fig. 2 Showing the difference of gathering rate between in the daytime and at night.

The fish were kept quietly in an aquarium for ten days before the experiments were started so they could become well acquainted with their surroundings.

As pointed out by many researchers, the degree of phototaxis of fish will be varied by other conditions such as temperature, chemical composition of the water, sex, mental state of fish, season, and the term or dark adaptation etc.

It would be difficult to fix definitely all these changeable conditions through the whole experiments, except the period of dark adaptation. However, many efforts have been done to keep conditions constant, and period of time allowed for the fish to become adapted to the darkness before the experiment was commenced.

Apparatus of Experiment

An aquarium, which is 300 cm. in length, 64 cm. in width, 40 cm. in depth, was prepared for this experiment in a dark room, and sea water (or fresh water) was poured into the aquarium to a depth of 8 cm.

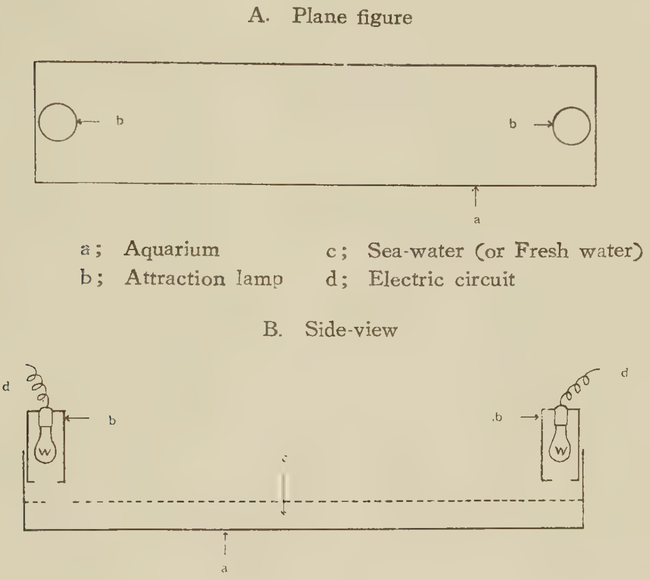


Fig. 3 Apparatus

To avoid reflection from the inner surface of the aquarium, the interior of it was painted black with a mixture of Indian ink and varnish which was harmless to the fish,

On each side of the aquarium, a cylindrical case, in which a Mazda electric bulb was inserted as a source of light and at the base of which was a hole 4 cm. square, through which light falls vertically upon the surface of the water, has been installed as shown in Fig. 3. And the source of light on each side was alternately lighted on and off at required intervals by a switch and the intensity of light was controlled by changing one bulb for another. At this time, the spectral radiant intensity emitted by each source of the light varied in each experiment, but such difference was regardless here.

Experiment

No. 1 Experiment — Mehod

First of all, we might come across the question what is the essential difference between the effect of the lamp system and that of a single lamp.

With the objective of giving a solution to this question, the authours hereby have commenced this experiment using the method described in detail below.

In the first place, 10 fish were quietly placed in the aquarium for each test and given 30 min. to become adapted to the begining of each test and

then the lamp at one side only was lighted, so the fish began to gather to the lamp in accordance with the intensity of phototaxis they have, while the authors carefully counted the number of the fish entering within a marked line every 30 seconds for 90 min. for the Mejina fish and for 100 min. for the Killifish.

In the next experiment, with a similar procedure, the lamps on the two sides, were alternately lighted on and off ten times at 10 minute intervals for the Killifish and nine times for Mejina fish. The fish came went between the two lamps at each time when the lamps were turned on and off, and the same measurements as above were taken in this case.

As the sources of light, Mazda electric bulbs of 40 W and 10 W were used for Killifish, and 40 W and 20 W for Mejina fish.

Each experiment was carried out four times to achieve accurate results. Hereafter, the term "Gathering Rate" which will be appear in the following chapters indicates the percentage of the number of fish gathered to the lamp within a marked lined which lies at the distance of 30 cm. from the lamp in comparison with the total number of fish.

Result

Results obtained from No. 1 Experiment are as follows :---

Aplocheilus latipes T. et S.

(1) Single lamp

a Using 10 W bulb.

Table 1

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	45.1	41.5	39.6	38.0	39.0	40.0	47.5	33.7	36.9	41.7

b Using 40 W bulb.

Table 2

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	36.0	31.0	34.3	30.1	37.1	32.0	29.1	36.1	39.7	41.0

(2) Lamp system

(a) Using 10 W bulb.

Table 3

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	55.5	43.9	47.8	46.8	44.4	41.6	43·8	40.1	39.1	41.0

(b) Using 40 W bulb.

Table 4

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	41.5	41.8	30.3	34.2	31.1	27.2	27.2	27.5	31.3	31.8

Table 1 and Table 2 are shown graphically in Figure 4, and Table 3 and Table 4 in Figure 5.

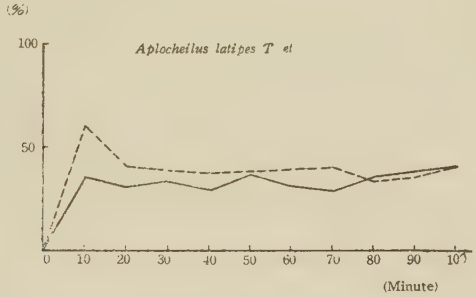


Fig. 4 Showing the relation between the gathering rate and the intensity by a single lamp.
Gathering rate vertical; Time horizontal;
— 40 W light bulb ----- 10 W light bulb

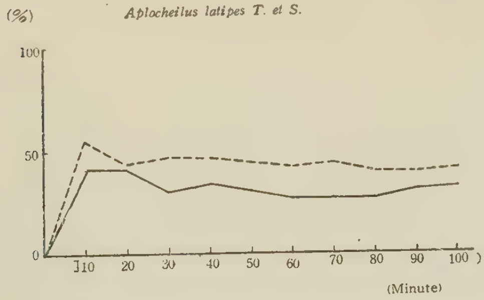


Fig. 5 Showing the relation between the gathering rate and the intensity by the lamp system.
Gathering rate vertical; Number of times when the lamps are turned on and off horizontal;
——— 40 W light bulb ----- 10 W light bulb

Girella punctata GRAY

(1) Single lamp

(a) Using 20 W bulb

Table 5

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	73.62	92.87	99.5	100.0	100.0	100.0	100	100.0	100.0	100.0

(b) Using 40 W bulb

Table 6

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	71.5	93.87	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(2) Lamp system

(a) Using 20 W bulb

Table 7

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	77.62	88.25	86.15	93.62	94.15	98.15	99.00	99.37	100.0	

(b) Using 40 W bulb

Table 8

Time (Minute)	I	II	III	V	V	VI	VII	VIII	IX	X
Gathering rate %	67.00	66.12	87.87	84.37	78.12	90.37	90.75	81.37	98.87	

Table 5 and Table 6 are shown graphically in Figure 6, and, Table 7 and Table 8 in Figure 7.

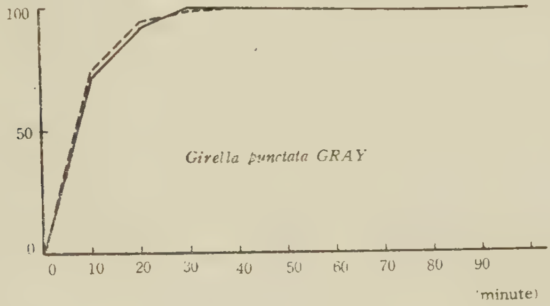


Fig. 6. Showing the relation the gathering rate and the intensity by a single lamp.
Gathering rate vertical; Time horizontal;
----- 40 W light bulb ——— 20 W light bulb

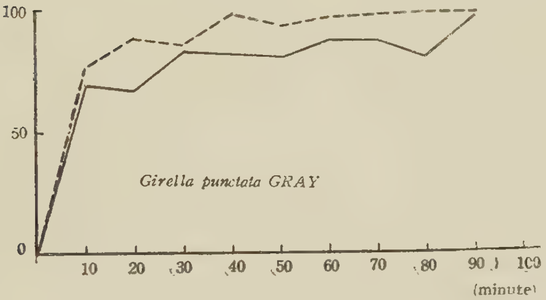


Fig. 7. Showing the relation between the gathering rate and the intensity by the lamp system.
Gethering rate vertical; Number of times when the lamps are turned on and off horizontal;
——— 40 W light bulb ----- 20 W light bulb

Discussion

Judging from the results obtained from No. 1 Experiment, in both cases of the lamp system and a single lamp, it is found that the lower intensity of light (viz. 10 W or 20 W) is more suitable for them than the higher one (40 W). It will therefore be supposed that the most appropriate intensity of light for them would be less than 10 W or 20 W.

As for the Killifish, the difference of the total average gathering rate between 40 W and 10 W, in the case of a single lamp, is 5,66 per cent, while 12.91 per cent in the case of the lamp system.

On the other hand, the Mejina fish shows only 0.11 per cent difference in the case of a single lamp, while 11.01 per cent in the lamp system.

In other words, in the case of Killifish, and Mejina fish as well, the

difference of the former is smaller than that of the latter. These facts indicate that the gathering rate in the lamp system will be affected by the intensity of light more than the case of a single lamp.

Comparing Fig. 4 with Fig. 5, of Fig. 6 with Fig. 7, in the case of the similar intensity of light, the average gathering rates of the lamp system seem to be slightly lower than that of a single lamp, except in the case of 10 W for the Killifish, which is 4.6 per cent increase over the single lamp.

These results suggest that, if the optimum intensity and time interval, which could be determined by a close investigation, were used, there would be a possibility of raising the gathering rate by the lamp system till almost the same as a single lamp, or higher.

For this reason, when we experiment with the lamp system, the intensity of light should be chosen more strictly than for a single lamp.

No. 2 Experiment — Method

As considered in the previonus experiment, the relationship between the lamp system and a single lamp has been clarified to some extent.

In this experiment the authors investigated the various influences of the intensities of light used and the intervals at which the lamps on the two sides of the aquarium are alternately lighted on and off upon the gathering rates.

The intensities of light which were used in this experiment are as follows:

40 W and 10 W for Killifish.

40 W and 20 W fou Mejina fish.

and the intervals are as follows:-----

10, 5, 3, 2, 1, (min.)---------for Killifish.

10, 5, 1, (min.)---------for Mejina fish.

(10 minute interval has already been done in No. 1 Experiment)

The methods of the procedures and measurements were the same as that of the previous experiment. But during the 1 min. and 2 min. tests observations were made and recorded every 15 seconds to improve the statistical value of the data.

Result

Results obtained from No. 2 Experiment are as follows:---

Aplocheilus latipes T. et S.

(1) Using 40 W bulb

(8) 5 min. interval

Table 9

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	15.0	22.25	30.00	25.75	30.25	29.25	30.00	26.75	26.79	27.75

(b) 3 min. interval.

Table 10

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	19.4	21.0	20.9	20.85	21.9	22.8	20.82	27.05	24.60	21.95

(c) 2 min. interval

Table 11

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	18.85	16.13	20.91	18.45	25.28	31.76	23.80	14.02	25.35	18.42

(d) 1 min. interval

Table 12

Time (Minute)	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	10.62	8.12	11.25	15.00	18.12	20.00	19.37	23.12	40.00	29.550

The above results are shown graphically in Figure 8.

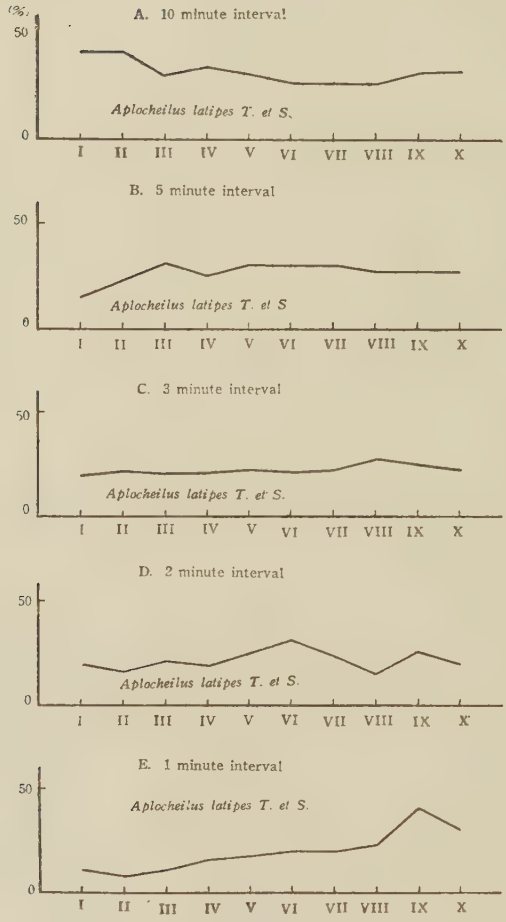


Fig. 8. A. B. C. D. E. Showing the relation between the gathering rate of *Aplocheilus* and the interval of time lighted on and off.
Gathering rate vertical; Number of times when the lamps are turned on and off horizontal;
(Used 40 W light bulb for the lamps)

Aplocheilus latipes T. et S.

(2) Using 10 W bulb

(a) 5 min. interval

Table 13

Number of times	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	44.50	39.50	35.25	39.25	39.75	37.50	43.25	33.50	36.50	30.75

(b) 3 min. interval

Table 14

Number of times	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	29.60	22.40	27.73	28.67	25.14	23.06	32.88	28.99	28.10	23.91

(c) 1 min. interval

Table 15

Number of times	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	36.66	40.00	48.33	38.00	38.33	37.50	40.00	36.76	35.00	44.16

The above results are shown graphically in Figure 9.

Girella punctata GRAY

(1) Using 40 W bulb

(a) 5 min. interval

Table 16

Number of times	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	67.00	64.75	78.00	75.75	84.00	85.75	90.50	89.75	94.22	—

(b) 1 min. interval

Table 17

Number of times	I	II	III	IV	V	VI	VII	VIII	IX	X
Gathering rate %	26.60	18.75	36.75	42.50	38.75	42.00	50.00	60.00	66.87	—

The above results are shown graphically in Figure 10.

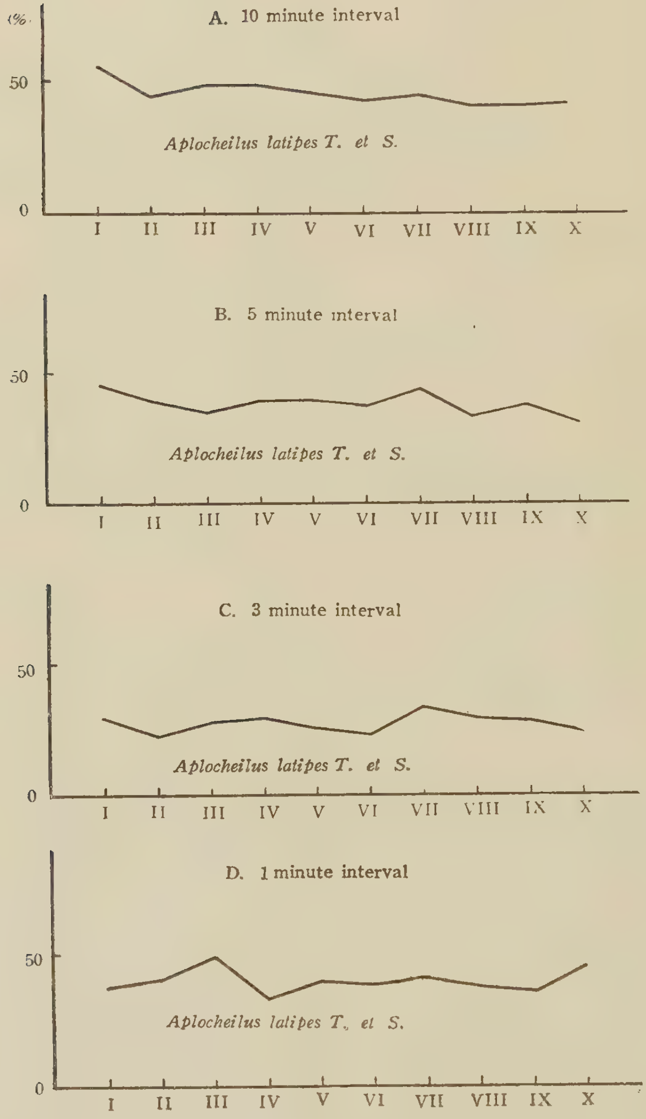


Fig. 9. A.B.C.D. Showing the relation between the gathering rate of *Aplocheilus* and the interval of time lighted on and off.
Gathering rate vertical; Number of times when the lamps are turned on and off horizontal;
(Used 10 W light bulb for the lamps)

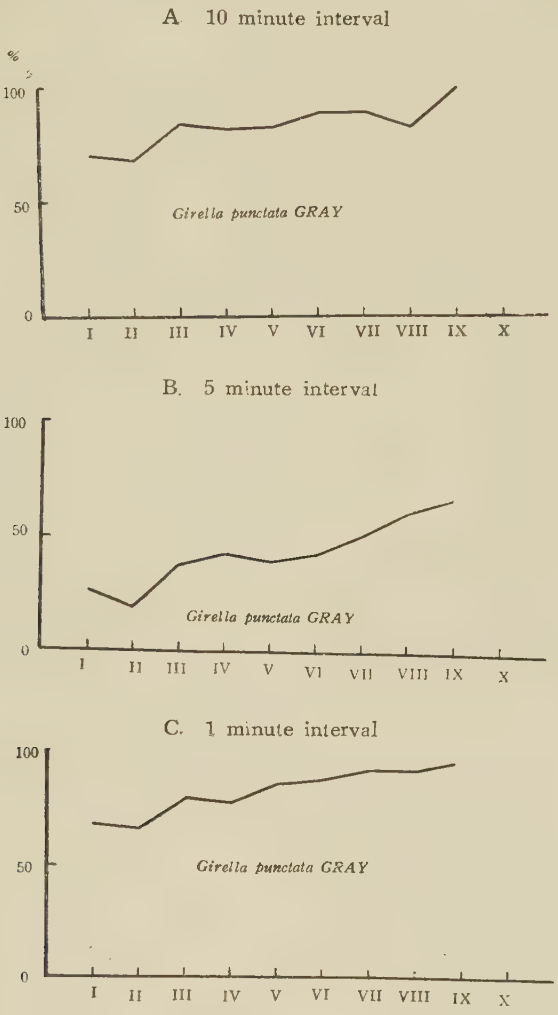


Fig. 10. A. B. C. Showing the relation between the gathering rate of *Girella* and the interval of time lighted on and off. Gathering rate vertical; Number of times when the lamps are turned on and off horizontal; (Used 40 W electric bulb for the lamps)

Girella punctata Gray

(2) Using 20 W bulb

(a) 5 min. interval

Table 18

Number of times	I	II	III	IV	V	V	VI	VIII	IX	X
Gathering rate %	78.75	85.50	96.75	97.50	99.50	99.50	99.50	100.0	1000	—

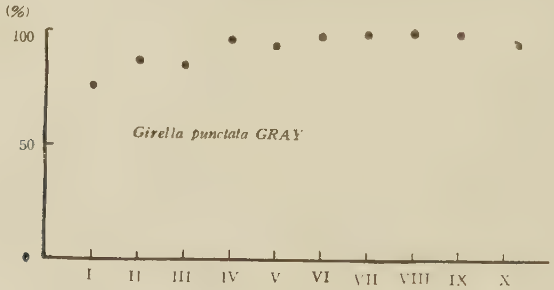
(b) 1 min. interval

Table 19

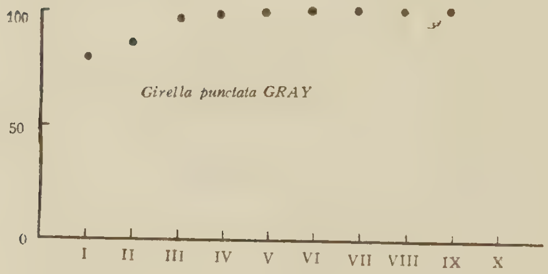
Number of times	I	II	III	IV	V	VI	VII	VIII	XI	X
Gethering eate %	57.50	66.00	71.90	64.90	65.62	64.40	78.75	81.90	83.15	—

The above results are shown graphically in Figure 11.

A. 10 minute interval



B. 5 minute interval



C. 1 minute interval

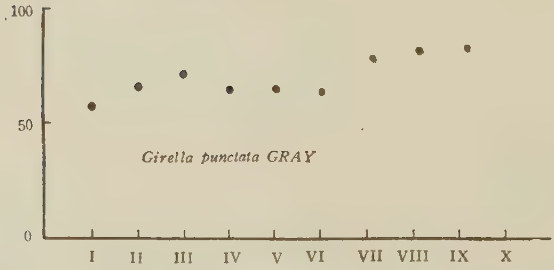


Fig. 11. A.B.C. Showing the relation between the gathering rate of *Girella* and the interval of time lighted on and off. Gathering rate vertical; Number of times when the lamps are turned on and off horizontal; (Used 20 W, light bulb for the lamps)

Discussion

The significant tendency observed from a comparison of Fig. 8 and 9 is that, when the interval is fairly long, the gathering rate of the Killifish decreases gradually in inverse proportion to the increase in the number of times the lamps are turned on and off, but, conversely, in the cases of the short intervals the gathering rates increased in proportion to the number of times the lights were turned on and off, especially when the intensity of the light was greater (40 W), even though the total average gathering rates decreased as the intervales became shorter.

Moreover, when we compare Fig. 10 with Fig. 11, the same tendency can be observed in the Mejina fish.

In interpreting the above data, the authors have concluded that the shorter the intervals the more the increasing rate of phototaxis is accelerated by the stimulus of the changing lights.

We have already observed in previous Chapter that the lower intensity (viz., 10 W for Killifish or 20 W for Mejina fish) is more suitable than the case of the 10 min. interval. And, here, as seen in following Table 20, the same results as above have been obtained for all intervals.

Table 20

Gathering rate (%) of fish at the time of interval and at the intensities of light.

Aplocheilus latipes T. et S.

Interval(Minute) / Intensity of light	10	5	3	2	1
40 W	31.99	26.37	22.98	21.38	19.51
10 W	44.90	37.97	27.04	—	38.96

Girella punctata Gray

Interval(Minute) / Intensity of light	10	5	3	2	1
40 W	82.4	81.08	—	—	42.52
20 W	93.15	95.22	—	—	70.51

Finally, the authors have come to the conclusion that if we select a light intensity as possible to the optimum value, the most satisfactory results would be obtained by the lamp system.

Although the total average gathering rates are gradually dropping in proportion to shortening of the intervals, with some exception as seen in Table 20, it is necessary to analize these results by another method. So the authors have compiled Table 21 which shows the relation between the gathering rate and the period of time for each interval in detail.

Table 21

Gathering rate of fish (%) at the time of interval lighted on and off.

Aplocheilus latipes T. et S. (10 W)

A. Period of Time (Minute)	0.30	1.00	1.30	2.00	2.30	3.00	3.30	4.00	4.30	5.00
10 minute interval %	45.7	50.0	47.0	46.0	42.0	41.2	38.0	43.0	40.0	47.7
5 minute interval %	36.5	41.5	37.5	42.5	40.7	37.0	36.5	36.2	38.7	36.7
3 minute interval %	28.3%	25.3	24.7	29.7	27.0	18.7				
1 minute interval %	45.7%	36.3								

Girella punctata GRAY (20 W)

A. Period of Time (Minute)	0.30	1.00	1.30	2.00	2.30	3.00	3.30	4.00	4.30	5.00
10 minute interval %	84.7	90.0	91.3	91.6	93.3	92.5	93.3	93.6	94.7	94.4
5 minute interval %	90.5	92.5	95.2	96.3	95.6	95.6	98.3	94.4	96.3	97.2
1 minute interval %	74.2	75.6								

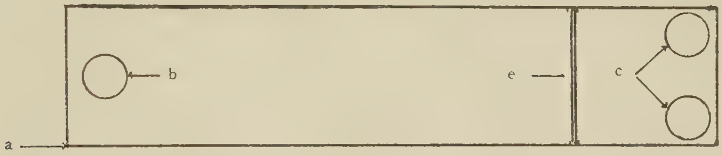
It is clear from these rusults that the gathering rates of 1 min. interval is higher than those of 2 and 3 min. intervals, and it is almost the same as that of the 5 min. interval, even though 7 to 10 per cent lower than that of the 10 min. interval. These results suggest that it may be possible, to raise the gathering rates even at the short interval or be sure of getting a greater amount of catch within a limited period than at the long intervals. It has also been observed that in a long interval the Killifish begin to gather at the light after the lamp is turned on and gradually increase for about one minute and reaches the maximum point and then tends to drop little by little and finaly settles at constant level. On the other hand, the Mejina fish gather rapidly when the light is first turned on and then continues to increase slowy and never down-

wards, and finally reaches the 100 per cent level. But, in a short interval both species are attracted to the lamps more swiftly than in the long interval because their reflex movements are accentuated by the sources of light on both sides, as is shown in Table 21.

No. 3 Experiment Apparatus and Method

The Mejina fish was used for this Experiment. Two sources of light were installed 30 cm. apart on one side of the aquarium which had the same dimensions as in the previous experiment. At a distance of 34 cm. from the cources of light a trap door was hung so that, when pulled down, the aquarium could not mave freely from one part to the other.

A. Plane figure



a; Aquarium
b; Adaptation lamp
c; Attraction lamp
d; Closure
e; Trap door
f; pulley
g; sea-water

B. Side-view

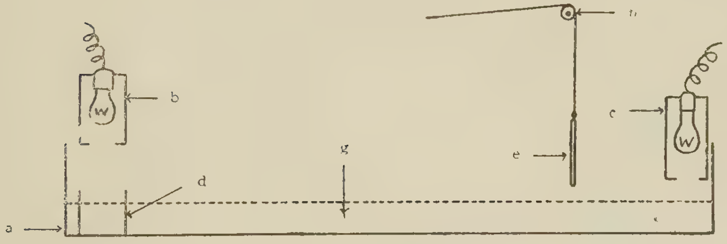


Fig. 12 Apparatus

On the opposite side of the aquarium, as shown in detail in Fig. 12, 40. cm. above the surface of the water was fixed an adaptation lamp (Fig. 12, b) by which the eyes of the fish were adapted to the various intensities of adaptation lights. Five fish (Girella punctata) for each test were compulsorily kept in a cylindrical inclosure placed right under the adaptation lamp.

After 30 minutes, the closure was taken away carefully and the fish set free. At the same moment two sources of light were switched on all at once

so some of the fish gather to the new light as soon as the adaptation lamp was turned off.

The authors counted the number of gathered fish and maked a calculation of the percentage. This test was repeated ten times in the same manner, and from these ten results the authors made a calculation of the average fish gathering rates.

It would be expected that the intensity of the adaptation lamp would affect the gathering rate during the period the after image of the first stimulus of light was effective, and also the intensity of the attraction lamp (second stimulus) would be relatively concerned with the first stimulus. From this point of view, the authors engaged in this experiment.

Result

Results obtained from No. 3 Experiment are as follows:---

(1) 100W for the attraction lamp.

Table 22

Number of Experi. / Intensity of adaptation lamp	1	2	3	4	5	6	7	8	9	10	Gathering rate % (Average)
Dark adaptation	0	2	0	0	2	0	0	0	0	0	8.0
2 Candle power	0	1	0	1	0	2	1	0	1	1	14.0
20 W	1	0	0	1	2	3	1	2	1	1	22.0
40 W	1	3	1	2	1	2	0	4	2	1	34.0
100 W	2	2	2	0	0	3	3	3	5	1	42.0

(2) 40W for the attraction lamp.

Table 23

Number of Experi. / Intensity of adaptation lamp	1	2	3	4	5	6	7	8	9	10	Gathering rate % (Average)
Dark adaptation	1	0	1	0	1	0	1	0	0	2	12.0
2 Candle power	0	2	0	2	1	0	2	1	0	2	22.0

20 W	2	1	3	2	1	3	1	2	1	2	36.0
40 W	4	3	1	2	3	1	2	2	1	3	44.0
100 W	1	0	4	5	4	3	2	1	5	5	60.0

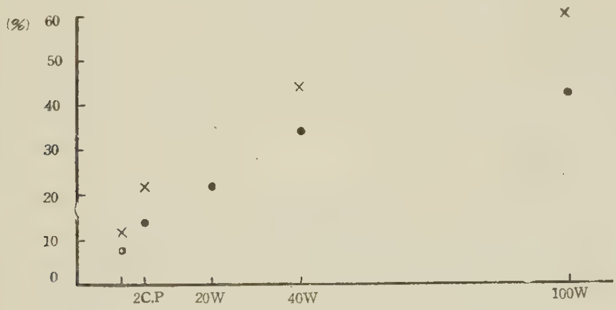
(3) 2 Candle power for the attraction lamp.

Table 24

Number of Experi. / Intensity of Adaptation Lamp	1	2	3	4	5	6	7	8	9	10	Gathering rate % (Average)
Dark adaptation	1	0	1	0	3	0	0	0	4	1	20.
2 Candle power	2	3	3	4	5	0	4	5	0	2	56.0
20 W	4	2	1	3	2	5	3	2	4	1	54.0
40 W	4	3	0	3	0	4	1	3	2	3	46.0
100 W	1	1	0	2	2	3	1	3	2	0	30.0

Tables 22, 23 and 24 are shown graphically in Figure 13.

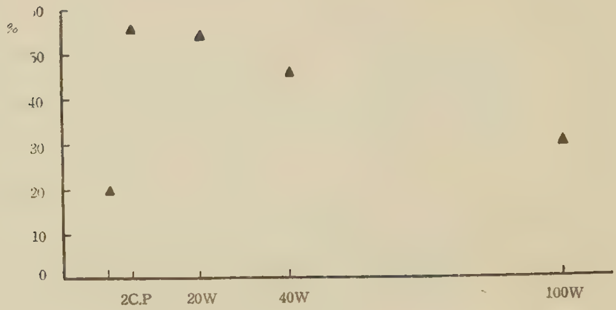
(A)



Dark adaptation
× 40 W light bulb for attraction lamp.
● 100 W light bulb for attraction lamp.

Gathering rate vertical; Intensity of the adaption lamp horizontal
Fig. 13. (A) (B). Showing the gathering rate of light-adapted *Girella punctata* GRAY to the various intensities of light.

(B)



Dark adaptation

▲ C. P; candle power W; wattage

2 candle power light bulb for attraction lamp.

Discussion

According to this result, the dark-adapted Mejina fish likes the lowest one (2 candle power) better than the other intensities of light used in this experiment, and, moreover, it is supposed that the most appropriate intensity seems to be less than that of 2 candle power. As curves a, b and c show, if the second stimulus of light was greater than the first, the gathering rates incline to reduce to a lower percentage, and on the other hand, if the second was smaller than the first, the same tendency as above case will be seen. But if the second stimulus is almost the same as the first, the gathering rates advance to the higher level, even though the intensities of both the second and first stimuli are greater than the Mejina fish usually prefers.

To explain this phenomenon, the authors should expect the first stimulus to cause the intensity of the second to diminish to some extent so long as the after image of the first stimulus lasts, and this diminution in the intensity of the second stimulus would depend roughly upon the intensity and duration of the first stimulus.

Therefore, during the after image of the first stimulus, the second one would not be recorded with normal intensity of light by the eyes of the fish and the fish mistakes the normal intensity of the attraction lamp for what is lower than the normal intensity and the fish gathers to attraction lamp according to this misjudgement.

The illustration considered above appears to explain well this phenomenon. If our eyes after being in almost dark are suddenly exposed to the light, at first the eyes are dazzled feeling too brighter than usual. The eye, however, becomes accustomed to the greater intensity.

On the other hand, on entering almost dark from the light, the eye cann't at first see anything feeling perfectly dark, but the objects begin to be recognized by degrees.

The experiment proves that the same phenomenon that occurs in the human eye could occur in the eye of a fish. Therefore, according to this fact, the distance between two lamps and the intensity of light, which is relatively concerned with the distance, will exert a great infulence, particurally at the short interval, upon the gathering rate in the early period before the first light stimulus disappears.

Summary

1) Although two lamps are turned on and off at any interval, it was found that *Aplocheilus latipes* T. et S. and *Girella punctata* GRAY show the greatest gathering rates to the lamps which have the most appropriate intensities for them.

2) It became clear that the gathering rate with the lamp system was affected more by the intensity than was a single lamp.

3) If the fairly long intervals were selected, we can expect to raise the gathering rate by the lamp system almost to the same or higher level as obtained with a single lamp.

4) The gathering rates, as a whole, decrease little by little in proportion to shortening of the interval, but the proper short interval brings forth profitable results in a limited period.

5) It is evident that the gathering rates raise in proportion to the rate of turning on and off of lamps, especially at the short interval.

6) While the after image of the first stimulus light lasts, the eye of *Girella punctata* GRAY does not record the intensity of the second stimulus light normally, but records it as brighter or weaker than the first stimulus light which serves as a temporary "false normal" basis of comparison.

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Vol. 1, No. 2, November 30. 1952.

THE CORRELATION BETWEEN WAVE LENGTH AND RADIANT ENERGY AFFECTING PHOTOTAXIS

(*With 7 Text-figures and 8 Tables*)

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Introduction

In the first report [KAWAMOTO & TAKEDA (1950)] the effect of wave length on phototaxis in several marine fishes was clarified, and among the eight lights, including white light and seven colored lights ranging from violet to red, either green or blue light produced the greatest fish gathering rate, even when their radiant energies were rather smaller than that of the others. As a result of a subsequent experiment, it has been seen that under two or more lights possessing the same spectral distribution, fish show a greater gathering rate for the light which has the larger radiant energy. Considering the results of both experiments, there can be no doubt, as stated by them, that the light-seeking tendency is much affected by wave length. However, the results of their work were not completely conclusive because they did not deal at length with the problem of what relation may exist between wave length and radiant energy in producing the effect of phototaxis. For the above reason the present study was made for the elucidation of this question at the Ichthyological Research Institute.

Materials Employed for Experiment

Two species of fish, caught near the Institute, were used for this experiment.

Species name	Body length (in cm.)
Sphaeroides rubripes T. et S.	1.6—2.0
Aplocheilus latipes (T. et S.)	2.5—2.6

Equipment for Experiment

The fish tank used was a lusterless, black painted square wooden tub, and its dimensions are given in Fig. 1. As the light source A.C. 40W light bulbs were employed, which were put in the tubes arranged at both sides of the fish tank and were placed at a distance of 10 cm. above the slit, and light was emitted downwards through the slit. As a means of obtaining colored light, Mazda-made color filters (V-B2, V-G1, V-Y1, V-R2) were attached over the slits, and in adjusting illumination screening papers (transparency 75%) were used.

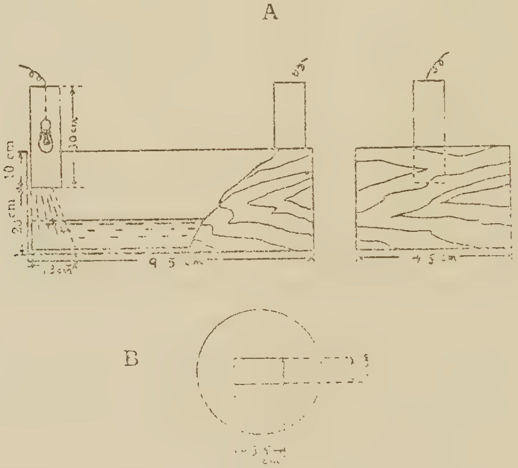

Fig. 1. Apparatus for experiment
A ·····Fish tank. B······Slit at the end of a tube.

Method of Experiment

The fish used in these experiments were kept in an aquarium for one week before the experiments were started. For each trial the ten fish were first placed in the fish tank while the laboratory was dimly lit. After thirty minutes, both bulbs were turned on simultaneously, and the measuring was promptly begun.

As for the method of measuring, the authors recorded the number of fish gathered in each illuminated field (13 cm. × 45 cm.) in every thirty seconds, and the recording was continued for ten minutes. During this experiment, in order to avoid the effect of schooling of the fish due to repeated trials, different fish were used for each trial.

With regard to the method of computation, the mean of the figures recorded through the above-mentioned measurments was converted into

percentage, and the authors propose to use the term "gathering rate" for these values. Although the color filter determined the spectral distribution of transmitted light, the radiant intensity varied with the different color filters. However, by adjusting the radiant intensity of the two lights carefully, a point where the fish showed equivalent gathering rates for both lights could be found. In these experiments, to fix the radiant intensity of either of the two lamps, the number of sheets of screening paper on one light or the other was varied in the neighborhood of such an intensity that the ratio of the gathering rates under the two lights became equal to unity. The five light combinations used were as follows: each of the four colored lights with white light, and green and red. During the experiment, the radiant energy of white light and that of green light only were changed in former and in later combinations respectively. In this case, one leaf of screening paper was constantly in the light whose intensity was not changed in order to make the quality of the two lights similar to each other.

Results of Experiment

The average results of the measurments determined by the above mentioned method are shown in Table 1 and Table 2.

Table 1

Species	*Sphaeroides rubripes*				*Aplocheilus latipes*			
Number of screening paper leaves	6	7	8	9	5	6	7	8
Gathering rate for white light (G_W)	32.3	31.2	27.4	20.5	27.7	21.5	19.2	18.0
Gathering rate for blue light (G_B)	19.8	22.8	28.6	33.8	22.1	22.0	22.6	28.0
G_B/G_W	0.61	0.73	1.04	1.64	0.80	1.02	1.18	1.56
Number of screening paper leaves	7	8	9	10	7	8	9	10
Gathering rate for white light (G_W)	26.7	23.0	24.2	17.7	23.9	25.0	19.0	16.7
Gathering rate for green light (G_{Gr})	17.0	22.4	23.3	24.5	16.7	20.2	20.5	23.8
G_{Gr}/G_W	0.63	0.93	0.97	1.38	0.67	0.18	1.08	1.42
Number of screening paper leaves	0	1	2	3	0	1	2	3
Gathering rate for white light (G_W)	27.8	23.4	20.2	14.8	26.8	25.2	22.9	19.8
Gathering rate for yellow light (G_Y)	16.0	21.6	26.5	22.5	19.8	23.5	25.4	29.4
G_Y/G_W	0.58	0.92	1.31	1.52	0.74	0.93	1.11	1.48
Number of screening paper leaves	10	11	12	13	13	14	15	16
Gathering rate for white light (G_W)	23.3	19.5	18.0	16.0	22.5	21.7	19.2	19.0
Gathering rate for red light (G_R)	15.8	13.9	17.2	19.5	14.5	16.0	18.5	22.0
G_R/w)	0.67	0.71	0.96	1.22	0.64	0.74	0.96	1.16
	Water temp. 16.1–17.0°C				Water temp. 18.5–19 3°C			

Table 2.

Species	*Sphaeroides rubripes*				*Aplocheilus latipes*			
Number of screening paper leaves	2	3	4	5	4	5	6	7
Gathering rate for green light (G_{Gr})	27.4	23.5	20.1	16.2	26.5	23.5	21.7	19.0
Gathering rate for red light (G_R)	14.3	23.0	22.7	24.3	15.5	18.2	20.5	22.0
G_R/G_{Gr}	0.52	0.98	1.13	1.50	0.58	0.77	0.94	1.16
	Water temp. 16.1–17.0°C				Water temp. 18.5–19.3°C			

In each case, decreasing the intensity of the light in the area in which the fish show greater aggregation in gradual steps by means of screening paper, inversion of phototaxis between the two lights can be observed: fish gathered at one light will migrate to the other.

Notation used in Table 1 and Table 2 are as follows:–

G: gathering rate, W: white light, B: blue light, Gr: green light,
Y: yellow light, R: red light

The number shown in the uppermost column denotes the difference between the numbers of screening paper leaves inserted in the two lamps.

Consideration

When phototaxis is considered only from the viewpoint of wave length, the conclusion stated in the first report may hold. As stated later on, however, taking a view of this from the following concepts, phototaxis seems to be always mutually influenced by both the wave length and the radiant energy.

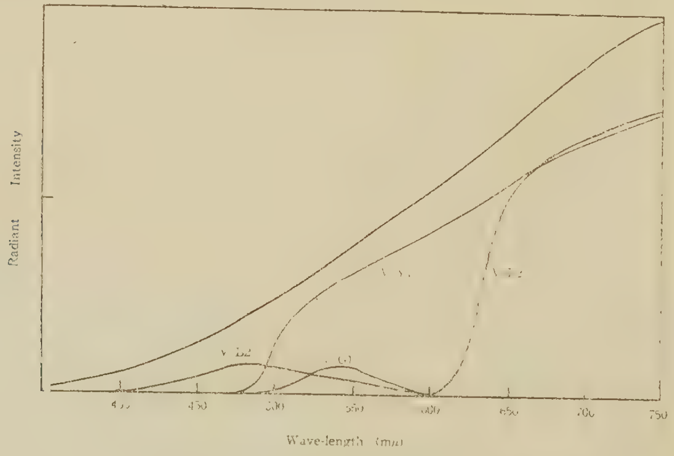

Fig. 2 Intensities of spectral radiation of lights emitted through color filters.

The total energy of transmitted colored light can be calculated from the energy distribution curve illustrated in Fig. 2, which was figured from the spectral radiant energy of a light bulb and transparency of the color filter. The values for all the colored lights are shown in the uppermost column in Table 8.

Because the spectrum of wave lengths longer than about 750 mμ do not contribute to the vision of fish, values only as far as 750 mμ were calculated and shown in Fig. 2.

By using E to represented the relative energy of transmitted light, D for transparency of screening paper per leaf, the light energy through both color filter and n sheets of screening paper, e may be given by

$$e=ED^n \qquad (D : 0.75)$$

Then the relative energy of each light at the time when the ratio of gathering rates became unity could be obtained by substituting the n calculated by the proportional allotment from the ratios of gathering rate. The ratios of relative energy of paired lights, in which relative energy of white light and that of green light are taken as unity, are shown in Table 3. By using e' notation of relative energy in the case of later light combination was distinguished from e.

Table 3

Ratio of radiant energy of transmitted light at the time when the gathering rate of fish for two lights were equivalent.

Sphaeroides rubripes	*Aplocheilus latipes*
$e_W : e_B = 1 : 0.62$	$e_W : e_B = 1 : 0.35$
$e_W : e_{Gr} = 1 : 0.64$	$e_W : e_{Gr} = 1 : 0.59$
$e_W : e_Y = 1 : 1.02$	$e_W : e_Y = 1 : 1.08$
$e_W : e_R = 1 : 13.44$	$e_W : e_R = 1 : 30.84$
$e'_{Gr} : e'_R = 1 : 20.50$	$e'_{Gr} : e'_R = 1 : 50.00$

Comparing $e_{Gr} : e_R$ gained through upper rows with $e'_{Gr} : e'_R$, it may be found that formula $e_{Gr} : e_R = e'_{Rr} : e'_R$ holds absolutely. Consequently, it may well be allowed to compare the energies of all the colored lights by means of the relative values shown in Table 3.

By plotting the logarithms of the reciprocal values of the relative energies shown in Table 4 against each color (B,G,Y,R) Fig. 3 was obtained.

This curve may be considered to be a kind of visibility curve, however, it is not known whether it is a rod or cone vision type curve. Then with

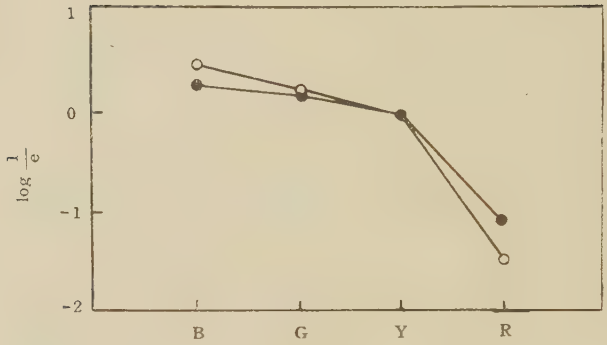

Fig. 3.

the idea of visibility being introduced for the elucidation of this subject, it may be expected that the quantitative relation between radiant energy and wave length affecting phototaxis may be easily explained. As has been stated by Hecht (1930) the visibility curve for fish is similar in shape to the curve of human vision, which is only displaced uniformly. So we substituted the human visibility curve (Fig. 4), displacing its muximum suitably for fish. In this case, therefore, although no curve to its propriety can be found, the authors employed the rod vision curve it agreed closely with the experimental results.

The product of the relative radiant energy (ϕ_λ) of light of a certain wave length λ and relative visibility (V_λ) for light of same wave length was generally called the "spectral luminosity" for the wave length, λ. Where the spectral distribution of light extended from λ_1 to λ_2 in wave length, total spectral luminosity (H) may be figured by the expression

$$H=\int_{\lambda_1}^{\lambda_2} \phi_\lambda V_\lambda d\lambda$$

Table 4

Sphaeroides rubripes	*Aplocheilus latipes*
$\log \frac{1}{e_B} = 0.2068$	$\log \frac{1}{e_B} = 0.4548$
$\log \frac{1}{e_{Gr}} = 0.1931$	$\log \frac{1}{e_{Gr}} = 0.2279$
$\log \frac{1}{e_Y} = \bar{1}.9912$	$\log \frac{1}{e_Y} = \bar{1}.9685$
$\log \frac{1}{e_R} = \bar{2}.8692$	$\log \frac{1}{e_R} = \bar{2}.5051$

The relative spectral luminosity values for each light were calculated by several visibility curves which were displaced wave length of maximal visibility to 500 mμ, 510 mμ, 520 mμ, 530 mμ and 540 mμ and are given in Table 5 and Fig. 5. In the experiment, white light was combined in turn with each colored light, and the spectral luminosity of the white light was adjusted by

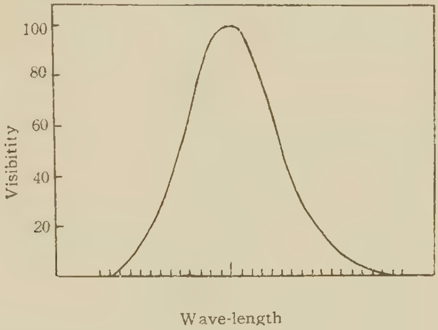

Fig. 4. Scotopic sensitivity curve of human.
Arbitrary units vertical.
Wave lengths horizontal, scales equal 10 mμs.

varying the number of sheets of screening paper on the light. Table 6 shows the variation of ratio of the spectral luminosity of white light to that of the partner lights (H_B/H_W, H_{Gr}/H_W, H_Y/H_W, H_R/H_W) by decreasing intensity.

Table 5

Connection of wave length of maximal visibility in visibility curve and spectral luminosity of each light

Wave length of maximal visibility	Spectral luminosity of every light				
	H_W	H_B	H_{Gr}	H_Y	H_R
500 mμ	600	106	47	333	5
510 mμ	643	101	53	410	9
520 mμ	707	99	61	463	14
530 mμ	770	85	62	525	24
540 mμ	846	80	70	595	44

Similarly, in the combination of green and red light, the variation of H_R/H_{Gr} is shown in Table 7. Where at, comparing Table 6 and Table 7 with Table 1 and Table 2, it may be found in the case of *Sphaeroides rubripes* that the number of screening paper leaves which were attached on one of the lights at the time when the ratios of spectral luminosity calculated from the visibility curve which has maximum at 530 mμ wave length become equal to

unity may show, in most cases, good agreement with that at the time when ratios of gathering rates will be unity. Similarly, in the case of *Aplocheilus latipes*, such agreement as above is seen when the muximum is assumed to be at 510 mμ. And in the above-mentioned visibility curve, if each of the maximal points is displaced by 10 mμ either towards the short or long wave lengths, it

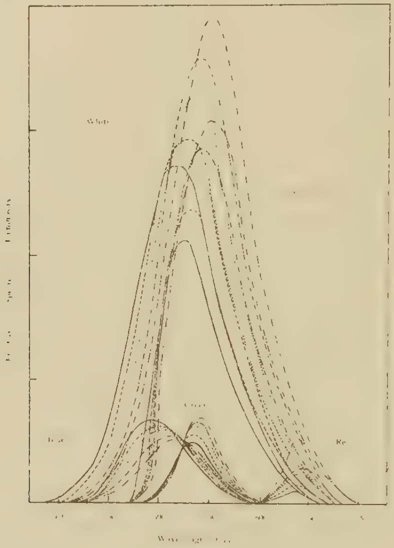

Fig. 5. Variation of spectral luminosity calculated by displacing of visibility maximum to arbitrary wave length.
—— visibility maximum is at 500mμ
--------- visibility maximum is at 510mμ
visibility maximum is at 520mμ
—•—•— visibility maximum is at 530mμ
—··—··— visibility maximum is at 540mμ

will be seen that these relations can scarcely be held. In other wards, under two lights which have equivalent spectral luminosity, fishes may gather equally in those lights. The relationship between the ratios of gathering rates of each colored light to that of white light (general notation: G_C/G_W) and ratios of those spectral luminosities (general notation: H_C/H_W) are expressed by the diagonal line (Fig. 6 & Fig. 7) and are given by

$$G_C/G_W = H_C/H_W$$

That is, *the ratio of gathering rates in two lights is equal to the ratio of the spectral luminosities of the two lights.*

In the combination of green and red light, assuming that the maximal visibility is at 530 mμ wave length in case of *Sphaeroides rubripes* and is at 510 mμ in case of *Aplocheilus latipes*, $G_R/G_G = H_R/H_G$, may also hold. These

Table 6

Variation of ratio of spectral luminosity of white light and colored light by decreasing intensity of white light.

Number of screening paper leaves	H_B/H_W						H_{Gr}/H_W				H_Y/H_W				H_R/H_W							
	5	6	7	8	9	10	7	8	9	10	0	1	2	3	9	10	11	12	13	14	15	16
Wave length of maximal visibility in visibility curve: 500 $m\mu$	0.75	0.99	1.33	1.77	—	—	0.59	0.78	1.04	1.38	0.56	0.74	0.98	1.32	—	—	—	—	—	0.50	0.63	0.83
510 $m\mu$	0.66	0.89	1.17	1.58	—	—	0.62	0.83	1.10	1.47	0.64	0.85	1.13	1.51	—	—	—	—	0.60	0.82	1.00	1.50
520 $m\mu$	0.59	0.79	1.05	1.39	—	—	0.65	0.86	1.15	1.53	0.65	0.87	1.16	1.55	—	—	—	0.64	0.82	1.08	1.56	—
530 $m\mu$	0.47	0.62	0.83	1.10	1.47	—	0.60	0.81	1.07	1.44	0.68	0.91	1.21	1.62	—	0.52	0.75	1.00	1.33	—	—	—
540 $m\mu$	—	—	0.72	0.94	1.25	1.67	0.62	0.82	1.09	1.46	0.70	0.94	1.24	1.67	0.69	0.92	1.22	1.63	—	—	—	—

Table 7

Variation of ratio of spectral luminosity of green light and red light by decreasing intensity of green light.

Number of screening paper leaves	H_R/H_{Gr}								
	0	1	2	3	4	5	6	7	8
Wave length of maximal visibility in visibility curve: 500 $m\mu$	—	—	—	—	—	—	0.63	0.83	1.00
510 $m\mu$	—	—	—	—	0.53	0.69	1.00	1.29	—
520 $m\mu$	—	—	—	0.54	0.74	1.00	1.27	—	—
530 $m\mu$	—	—	0.69	0.92	1.20	1.60	—	—	—
540 $m\mu$	0.63	0.83	1.10	1.47	—	—	—	—	—

relations seem to perhaps hold independently of the wave length, and it has been found that when two lights having equivalent energy were turned on, the gathering tendency depended on the spectral distribution of light; fish will gather in the light possessing the spectrum of higher visibility. On the other hand, turning on two lights possessing the same spectral distribution, the situation is dominated by the radiant energy factor.

Thus because the gathering tendency is dependent upon the spectral luminosity, if the radiant intensity only is increased, even the colored lights which attract fish very little (red, violet etc.) can produce the same gathering rates as the colored lights which attract very strongly (green, blue light etc). In our experiment, however, we have dealt with the ratio of gathering rates for two lights, but as for the fish gathering reaction for only one light it may be impossible to explain quantitatively by the idea of the spectral luminosity. And if the one of two lights have a higher or lower brightness than the other

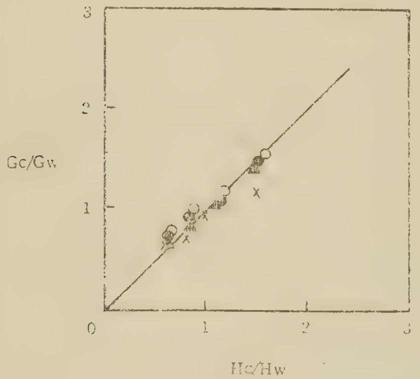

Fig. 6. Showing the relationship between ratio of fish-gathering rate ($G_{C/W}$) and the ratio of spectral luminosity (H_C/H_W). *Aplocheilus latipes* (T. et S.)

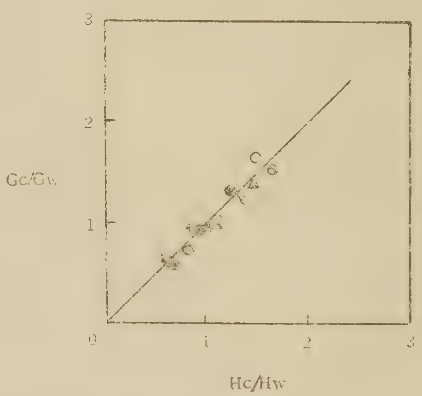

Fig. 7. Showing the relationship between ratio of fish-gathering rate (G_C/G_W) and the ratio of spectral luminosity ($H_C/_W$). *Sphaeroides rubripes* (T. et S.)

beyond a certain bound, relation given above seems to be scaresly hold because of another factors will participate in this subject.

Both the absorption spectra of visual purples and the visibility curves of the fish used have not yet been determines. The true nature of the curve, called "visibility curve" of fish in this paper, must be investigated and considered from other aspects. C. HESS (1912) observed that the visibility curve of fish shows fairly good agreement with human rod vision visibility curve, and H. GRUNDFEST (1932) also studied the problem of visibility in fish by the method of behavioral discrimination. In view of these facts, it seems to be not necessarily unreasonable to introduce the concepts about visibility for

elucidating these subjects, and our so-called visibility curve seems to be a rod vision type curve. But it is uncertainly whether the true one. For that reason, as to the true nature of the curve, there is nothing for it but to conjecture.

Next the ratios of relative spectral luminosity to relative radiant energy, $\int\phi_\lambda V_\lambda d\lambda/\int\phi_\lambda d\lambda$, was called "visual efficiency" and are gained from Fig. 2 and Table 5. (Table 8)

Table 8

Visual efficiency

		White	Blue	Green	Yellow	Red
	$\int\phi_\lambda\, d\lambda$	4892	186	100	3464	2179
Sphaeroides rubripes	$\frac{\int V_\lambda \phi_\lambda\, d\lambda}{\int\phi_\lambda\, d\lambda}$	0.16	0.46	0.62	0.15	0.01
Aplocheilus latipes	$\frac{\int V_\lambda \phi_\lambda\, d\lambda}{\int\phi_\lambda\, d\lambda}$	0.13	0.54	0.53	0.12	0.004

In the case of *Sphaeroides rubripes* green light shows the largest visual efficiency, that of blue light is next to green and that of red light is smallest. Though radiant energy of red light is 22 times as much as that of green light, its visual efficiency is no more than 1/62 of that of green light. In the case of *Aplochelius latipes* that of blue and green light are equivalent and that of red light is extremely small. Differences with different kinds of fish may be easily understand from the fact that the visibility curve of *Aplocheilus latipes* is displaced towards shorter wave length than that of *Sphaeroides rubripes*.

Summary

1 The product of the radiant energy of light of certain wave length and the visibility to that light was called "spectral luminosity" for the same wave length.

2 When the spectral luminosity was calculated by using the human visibility curve with the maximum displaced suitably as a substitute for the true visibility curve of fish, the ratio of the gathering rates for the two lights is proportional to the ratio of the spectral luminosities of the two lights.

3 Judging from our experiments by the method of behaviorism, it seems that the visibility curves of *Aplocheilus* and *Sphaeroides* possess maxima at about

510 mμ and 530 mμ respectively. It is not yet certain whether above-mentioned curve is the true visibility curve, but it appears to correspond to such a curve as HESS and GRUNDFEST obtained.

5 From the ratio of spectral luminosity to radiant energy, the "visual efficiency" was calculated.

In conclusion, the authors wish to express their sincere gratitude to Mr. BINZO MURUYAMA, President of the Fisheries Research Institute, who granted a subsidy of that Institute and also to Dr. YAICHIRO OKADA, Dean of the Faculty of Fisheries, Prefectural University of Mie, and Dr. K. MATSUBARA, professor of Kyoto, University for their kind suggestions.

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COLORIMETRIC DETERMINATION OF BROMINE IN THE MARINE ALGAE

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Because algae are being considered as a source of bromine, the authors wish to report a simple colorimetric quantitative method for the determination of bromine in algae. This method was developed to determine the amount of bromine in several species of the genus *Polysiphonia* (*Rhodophyceae*) during the monographic and systematic study of this genus by the senior author.

The quantity of bromine in the several marine algae that belong to this genus was determined by this method, and some of the information which was learned in this research will also be reported.

There is very little literature referring to the exact determination of the quantity of bromine in marine algae. Up to this time, the Pincussen, Roman Method and the Indovina Method are the well known standard methods for the determination of the quantity of bromine in organic matter.

In the Pincussen, Roman Method, an amount of KOH equal to five times the quantity of the dry sample is added to the sample in a nickel crucible and heated until the whole mixture is melted; all the halogen elements are thus changed to potassium salts. Water is then added to the melted matter and it is again heated to dryness. Then KI is extracted from the dry material with alcohol. The remaining residue is dissolved in water and acidified with nitric acid, and after adding hydrogen peroxide, chloroform is added and the free bromine shifted into the chloroform. Then KI solution is added and the amount of separated iodine is titrated with 0.001 N solution of sodium thiosulfate.

In the Indovina Method, which was developed for the determination of the very small amount of bromine in blood, KOH and MgO is added to the dry sample and the mixture heated until only the ashes of the algae sample remains. The ash residue is then dissolved in water and the solution acidified, and chlorine water is added. The fuchsin sulfurous acid solution is then oxidized by the bromine and the color of the fuchsin determined. In the Indovina Method, the coexistence of iodine and other halogen elements

does not interfere with the determination of bromine, but the PINCUSSEN, ROMAN Method requires the separation of the various halogen elements and so is a long complex procedure.

It must be realized that actually the coexistence of many chlorides and iodides is to be found in marine algae, and moreover it should be possible to deal with the various sorts of samples simply and precisely, and also a feasible method ought to be developed for determining larger amounts of bromine than the INDOVINA Method is suited for because rather large amounts of bromine are found in all the algae, and especially the *Rhodophyceae* species, as will be mentioned later.

Recently SHIRAHAMA, SASA and UNO (1944) investigated the following method for the accurate determination of bromine in algae. They proposed that the best way to reduce the dry algae (powder) to ashes is to add sodium carbonate and heat the mixture at more than 250°C. for six hours. Then add dilute sulfuric acid and hydrogen peroxide solution to the solution (extracted in water) of ashed mixture and shift the separated iodine into chloroform or carbon tetrachloride. The remaining solution is then treated with sulfuric acid and chrome anhydride, and the separated bromine is titrated with 0.001 N solution of sodium thiosulfate. But this method is the separating method of determining the quantities of all halogen elements, and it is somewhat complex.

In the method developed by the authors, a solution of the marine algae ash is made by approximately the same method used by SHIRAHAMA, SASA and UNO. The solution is then acidified with dilute sulfuric acid and a small amount of chlorine added. Iodine then separates out. Then a large amount of chlorine water is added and colorless iodic acid is formed and the solution becomes colorless.

Next the colorimetric method for the determination of free bromine was adopted. The liberated bromine was shifted into chloroform or carbon tetrachloride where it appeared as a brown solution. When an excess of chlorine water is added to the mixture, great care must be taken that the color in the chloroform does not fade due to the formation of yellowish Cl-Br. The process of this reaction is as follows:

First reaction	$I' \longrightarrow$	$I_2 \longrightarrow$	IO'_3
	(colorless)	(purple)	(colorless)
Second reaction	$Br' \longrightarrow$	$Br_2 \longrightarrow$	$Cl\text{-}Br$
	(colorless)	(brown)	(yellow)

This color reaction is unstable and can not be preserved for a long time, but the authors were amply able to determine the color if done without delay. The authors determined the concentration of bromine by comparing the color

of the bromine that was shifted from a definite amount of the solution of the marine algae ash to a definite amount of chloroform or carbon tetrachloride with the color of the bromine that was shifted into chloroform or carbon tetrachloride by adding simultaneously the same treatment to the standard solution which was made from ordinary KBr salt. The DUBOSQ colorimeter was used to compare the colors.

The authors found that this method is never disturbed by the coexistence of many chloride and iodide ions, and it is a simple and a precise method.

Furthermore, it is possible to determine, at the same time, the amount of iodine in the marine algae by this colorimetric method by using the remaining solution after the determination of the amount of bromine. To do this the authors determined the color of the iodine which was shifted into a definite amount of chloroform or carbon tetrachloride by acidifying a definite amount of the test solution with dilute sulfuric acid and adding hydrogen peroxide solution. Thus only iodine is separated even though bromine is still present. Then the color of iodine which was shifted into chloroform or carbon tetrachloride is compared with the standard solution made from ordinary KI by the same treatment. The color measurements were made with the DUBOSQ colorimeter and later the readings were compared.

That bromine exists in marine algae was reported by KYLIN (1929), one of the foremost algologists in Sweden, but his research was not quantitative. However, SHIRAHAMA, SASA and UNO have reported the amount of bromine contained in many species of marine algae belonging to *Chlorophyceae*, *Phaeophyceae* and *Rhodophyceae* comprehensively.

Their investigations showed that the bromine content of marine algae, especially in *Rhodophyceae*, is much greater than was expected. Especially 2 to 4% of the ash of the marine algae, *Rhodomela larix* (TURN.) J. AG. (Japanese name, *Fujimatsumo*), and 6.54% in *Odonthalia corymbifera* (GMEL.) J. AG. (Japanese name, *Hakesaki-nokogirihiba*). The amount of iodine contained in the ash of *Fujimatsumo* and *Hakesaki-nokogirihiba* is 0.02%. It is generally understood that a much larger amount of bromine than iodine is contained in marine red algae. Generally, the brown algae, *Phaeophyceae*, contain a fair amount of iodine, but *Laminaria* has the highest iodine content, 0.6% of the ash. In contrast to this, the bromine content is higher in red algae, *Rhodophyceae*, and this fact seems to have some relations to the physiological problem of this group. KYLIN also insists upon the existence of bromine in marine algae in the form of organic compounds, because he found bromine in the solution of the marine algae ash easily, but was unable to detect it in a solution of the juices pressed from the algae. The genus *Polysiphonia*, which is studied in this research, belongs to the *Rhodophyceae* and is found to contain

a large amount of bromine also. Data obtained in this research is shown in the following table.

Species	Place and date	Ash%	Bromine in ash %	Iodine in ash %	Bromine in dry sample %	Iodine in dry sample %
Polysiphonia Morrowii HARVEY (*Moro-itogusa*)	Asamushi May 9, 1944	25.33	5.057	0.130	1.2809	0.0329
P. urceolata (DILLWYN) GREVILLE (*Syozyo-kenori*)	Asamushi May 9, 1944	27.90	5.008	0.098	1.4002	0.0274
P. urceolata (DILLWYN) GREVILLE (*Syōzyo kenori*)	Shinmaiko April 14, 1944	40.24	3.307	0.030	1.4021	0.0120
P. japonica HARVEY (*Kiburi-itogusa*)	Ikawatsu July 24, 1944	34.80	4.070	0.057	1.4188	0.0198
P. nipponica SEGI (*Nippon-itogusa*)	Komi May 10, 1944	60.56	2.328	0.007	1.4138	0.0042

The authors wish to express their hearty thanks to Prof. Y. YAMADA of Hokkaidō University for his valuable assistance and to Prof. Y. ITō of Tokyo University for his courteous suggestions in preparing this paper.

Procedure for the Determination of Bromine

I Preparation of the algae ash

After collecting, the sample materials were allowed to dry in the air, then ground into a powder and left in a drier for two days. In order to prevent the volatilization and loss of bromine and iodine in the high temperatures necessary to reduce the dry powder of the marine algae to ashes, the sample was immersed in 10 cc. of sodium carbonate solution (10% solution of $Na_2CO_3 \cdot 10H_2O$), and drying and subsequent heating was done at as low a temperature as possible, at about 400°C., for 4 to 5 hours. Then the sample was allowed to cool in a desiccator and weighed. Then it was heated for an hour again, cooled in a desiccator, and weighed. This was continued until a constant weight was reached. The weight of ash was then found by subtracting the weight of Na_2CO_3 from the final weight of the dried mixture.

II Preparation of the solution

Distilled water was then added to the ash residue and heated to boiling. After the insoluable materials had settled, the solution was removed from the mixture by decanting. This was repeated several times, and finally the

last insoluable material was removed by filtering, and the residue washed until the filtrate showed negative in halogen ion reaction with $AgNO_3$ solution. The washing solution (filtrate) was then added to the decanted solution and the total amount of the solution reduced (or incleased) to exactly 100 cc. Although the solution might be colored, this was never interfered to the exact determination of the amount of bromine because this color never shifted into the chloroform or carbon tetrachloride.

III Determination of the exact amount of bromine

a. Preparation of the standard solution of bromine.

A solution of 0.5g. of KBr in 1 liter of distilled water is called the Standard Solution of bromine.

b. Determination of the exact quantity by use of the colorimeter.

1 Preliminary test:

First. exactly 10 cc. of the test solution and 10 cc. of the standard solution were measured out. Then, 5 cc. of dilute sulfuric acid (1:1), 10 cc. of distilled water, 0.5 cc. of chlorine water and 5 cc. of chloroform or carbon tetrachloride was added to each solution, and shaked and color of the chloroform or carbon tetrachloride layers were compared. If the colors are nearly the same, they can be compared directly by the colorimeter readings, but if the test solution shows a much darker color than the standard solution, a more favorable concentration of the test solution must be found by diluting the test solution to 1/2, 1/4, or 1/8 of its original concentration. The amount of chlorine water, 0.5 cc., is sufficient for this density in the standard solution, but in other case other densities are required, a series of tubes (standard solution) containing an added 0.1, 0.2, 0.3 etc. up to 1.0 cc. of chlorine water is made and the darkest color of the chloroform or carbon tetrachloride layer is adopted. If the layer of chloroform or carbon tetrachloride becomes murky or cloudy, more chloroform or carbon tetrachloride was added.

2 The main test:

The chloroform or carbon tetrachloride layer is drawn off from both solutions by means of separation funnels and the colors determined with a Dubosq colorimeter.

In 1 cc. of the standard solution 0.0005 g. of KBr is found. If the length of the column (a) of the standard solution and the length of the column (b) of the test solution are compared with each other, the amount of KBr in 1 cc. of the test solution is $0.0005\frac{a}{b}$ g., and the amount of Br_2 in 1 cc. is $0.0005\times\frac{a}{b}\times\frac{79.92}{119.02}$ g. In 10 cc. there will be 10 times as much Br_2. The complete formula is given as follows:

$$\text{Amount of } Br_2 \text{ in marine algae ash } (\%) = \frac{0.0005 \times 10 \times a/b \times 79.92/119.02 \times 100/10}{\text{weight of ash in the sample}} \times 100\%$$

$$= \frac{3.35742}{\text{weight of ash}} \times \frac{a}{b}\ \%$$

IV Determination of the exact amount of iodine.

a. Preparation of the standard solution of iodine.

A solution of 0.5 g. of KI in 1 liter of distilled water is called the standard solution of iodine.

b. Determination of the exact amount of iodine by use of the colorimeter.

1 Preliminary test:

First, exactly 10 cc. of the test solution and 10 cc. of the standard solution were measured out. Then 5 cc. of dilute sulfuric acid (1:1), 10 cc. of distilled water, 1 cc. of hydrogen peroxide and 5 cc. of chloroform or carbon tetrachloride was added to each solution and shaked and compare the colors in the chloroform or carbon tetrachloride layers. If the colors of the two layers are approximately equal, they can be compared directly. If the test solution is extremely dark, it must be diluted to 1/2, 1/4, or 1/8 its original concentration until the colors are suitable to be examined.

2 The main test:

The chloroform or carbon tetrachloride layer is drawn of both solutions by means of separation funnels, and the colors determined with a DUBOSQ colorimeter. In 1 cc. of the standard solution is 0.0005 g. of KI. If columm (a), standard solution, is balanced with column (b), test solution, the amount of KI in 1 cc. of the standard solution is $0.0005 \times \frac{a}{b}$ g., and the amount of I_2 of the test solution is $0.0005 \times \frac{a}{b} \times \frac{126.92}{166.02}$ g., and the amount in 10 cc. of test solution will be 10 times this amount. The complete formula is given as follows:

$$\text{Amount of } I_2 \text{ in marine algae ash } (\%) = \frac{0.0005 \times a/b \times 10 \times 126.92/166.02 \times 100/10}{\text{weight of ash in the sample}} \times 100\%$$

$$= \frac{3.82243}{\text{weight of ash}} \times \frac{a}{b}\ \%$$

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PRELIMINARY REPORT ON EXPERIMENTS WITH SMALL TRAWL NETS

I FORM OF SMALL TRAWL NET

(*With 2 figures and 5 Tables*)

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The question of the relationship between the changes of the height and width of the entire bag* in proportion to the difference of beam length and pulling velocity have been studied by means of a small trawl net (6 HP) used in Osaka Bay.

Table 1. (Height) (in m)

Pulling Velocity	Beam length \ Measure point	9	8	7	6	5	4	3	2	1
1/5 m/h	3.8	.70	.85	.88	.90	.83	.83	.83	.80	.75
	4.5	.60	.85	.80	.80	.75	.73	.70	.70	.60
	5.3	.60	.75	.70	.75	.70	.70	.70	.65	.60
	6.1	.60	.70	.70	.73	.70	.70	.70	.65	.52
1/2 m/h	3.8	.55	.75	.70	.75	.70	.70	.65	.60	.55
	4.5	.55	.75	.70	.75	.70	.70	.70	.65	.60
	5.3	.55	.68	.65	.65	.60	.58	.55	.55	.50
	6.1	.50	.60	.60	.60	.60	.60	.55	.55	.50
1 m/h	3.8	.50	.65	.65	.65	.60	.60	.60	.50	.50
	4.5	.50	.65	.65	.70	.65	.63	.60	.55	.50
	5.3	.50	.60	.62	.65	.65	.63	.60	.55	.50
	6.1	.40	.50	.60	.60	.55	.55	.55	.55	.50

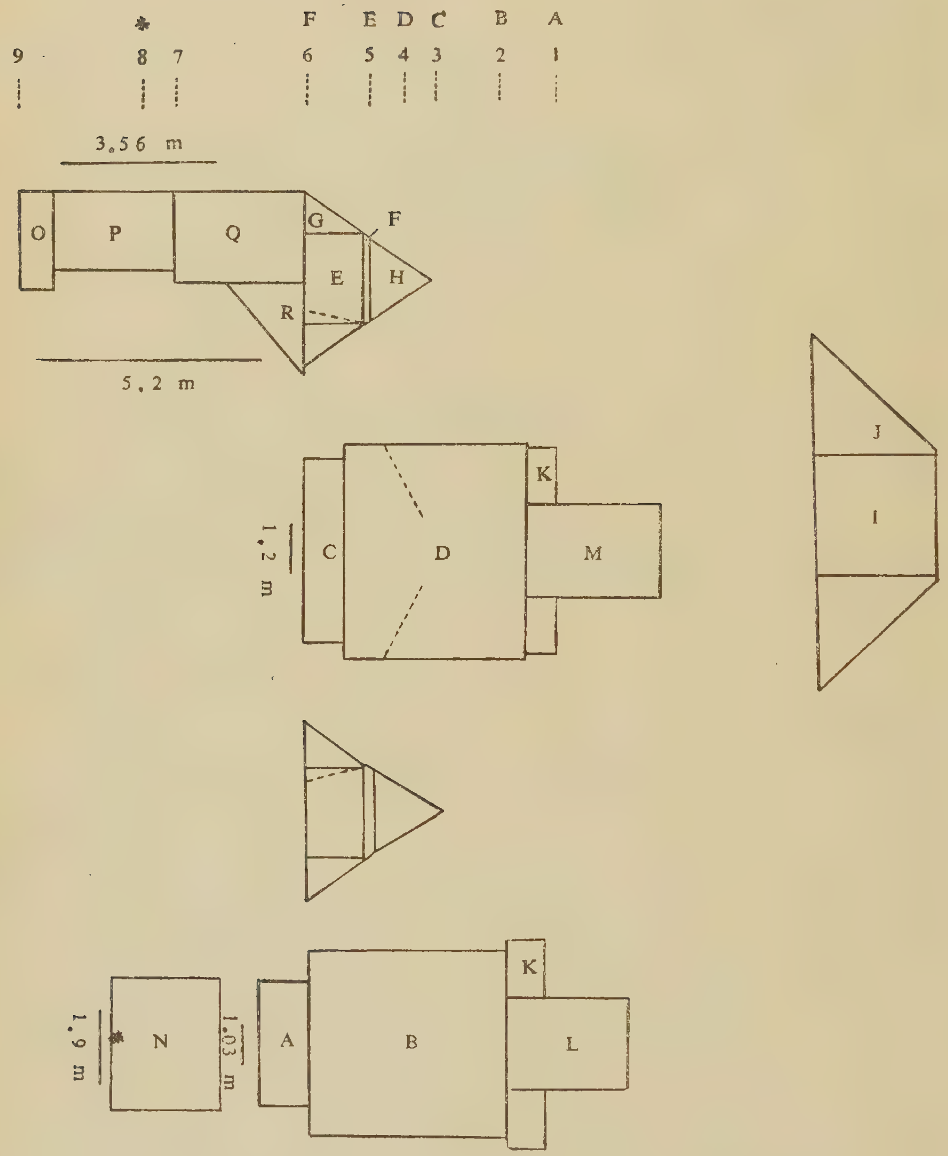

Fig. 1. Detail of small trawl net and materials used for making. $\frac{1}{150}$

The construction of the net is shown in Fig. 1.

The experiments were carried out at Sumoto Bay (depth, 3 meters; bottom material, sand; specific gravity of the sea water, 1.023–1.024). (The specific gravity of the sea water was measured wish AKANUMA's hydrometer.)

The length of the warp was 38 meters, and at a point along the hand

ropes 1 meter from the plum staves the beam was attached to hold the mouth of the net in a fixed position.

Many tests were made in this experiment. The net was pulled in the same direction as the current flowed (favorable current velocity of from 0.1 to 0.15 m./h.), and various length beams (3.8 m., 4.5 m., 5.3 m., and 6.1 m. , were used.

In these tests the pulling velocity was measured by a hand log from the stern of the towing boat.

The height from the bottom to the float line at both ends of the wings, and the maximum height of any point of the entire bag were measured with the lead line, and the width of any point of the entire bag was measured with a measuring pole which was lowered by ropes from the boardside of a boat which moved directly above the net during the tests. (Tab. 1-2).

Table 2 (Width) (in m)

Pulling Velocity	Beam length \ Measure point	F	E	D	C	B	A
$\frac{1}{5}$ m/h	3.8	1.3	1.0	.95	.90	.90	.90
	4.5	1.9	1.3	1.15	1.0	.90	.90
	5.3	1.9	1.3	1.15	1.0	.95	.95
	6.1	1.9	1.4	1.2	1.0	.95	.95
$\frac{1}{2}$ m/y	3.8	2.0	1.34	1.2	1.06	.90	.95
	4.5	2.0	1.4	1.2	1.0	.90	.95
	5.3	2.0	1.5	1.35	1.2	1.0	1.0
	6.1	2.3	1.6	1.5	1.1	1.0	1.0
1 m/h	3.8	2.04	1.6	1.2	1.0	.90	1.0
	4.5	2.3	1.5	1.2	1.0	.90	1.0
	5.3	2.2	1.6	1.3	1.0	1.0	1.1
	6.1	2.3	1.6	1.3	1.0	1.0	1.1

In the tables and formulas, r_u and r_y denote the relative tensions of the net along the mid-line on the upper and lateral sides of the entire bag respectively ; ρ_u and ρ_y denote the radii of curvature of the upper and lateral sides at the maximum point (height and width) at any one section of the entire bag when the cross section of the entire bag may be regarded to have

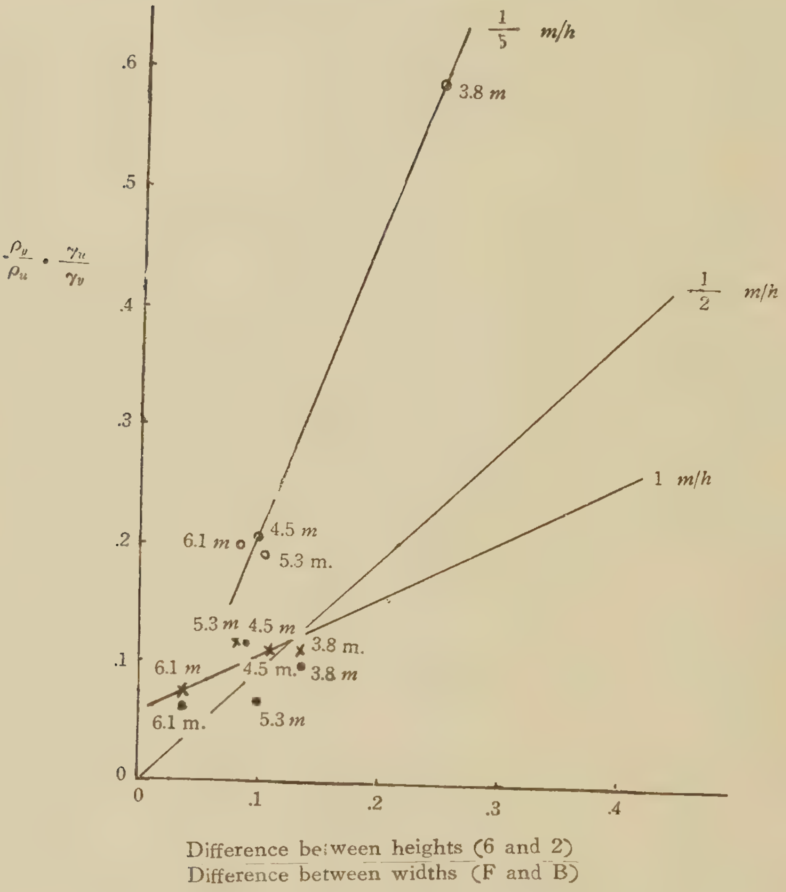

Fig. 2. The relation between $\rho_y/\rho_u \cdot \gamma_u/\gamma_y$ and $\sin\theta_u/\sin\theta_y$.

the shape of an ellips, and θ_u and θ_y denote the angles between the direction of the movement of the net and the upper and lateral sides of the net respectively.

The results shown in Tables 3,4 and 5 and in Fig. 2 give the values for ρ_y/ρ_u r_u/r_y and sin θ_u, sin θ_y for each pulling velocity calculated according to Dr. TAUTI's formula**.

Fig. 2 shows that a direct line can be drawn through the original point only when the pulling velocity is 1 2 m. h. when the pulling velocity is 1 m. h, a line can not be drawn directly through the original point, that is, only when the point of the beam length (6.1 m.) is out of the place from the line, compared with the case of 1/2 m./h.

The above mentioned fact shows that the from of the entire bag may be changed irregularly, and the change in form is most pronounced at the highest pulling velocity.

$\rho_y/\rho_u \cdot r_u/r_y$ and sin θ_u/sin θ_v are equal when the pulling velocity is 1/2

Table 3 (Pulling velocity, 1/5 m/h)

Beam length	6.1 m	5.3 m	4.5 m	3.8 m
Difference between heights (6 and 2)	.08	.10	.10	.10
Difference between heights (6 and 9)	.13	.15	.20	.20
Total	.21	.25	.30	.30
γ_u	1.00	.84	.70	.70
Height of 7	.70	.70	.80	.88
γ_y	1.00	1.00	.88	.80
$\frac{\gamma_u}{\gamma_y}$	1.00	.84	.80	.88
Height of 4 (H)	.70	.70	.73	.83
Width of D (B)	1.2	1.15	1.15	.95
$\frac{\rho_y}{\rho_u}=\left(\frac{H}{B}\right)^3$	.198	.226	.256	.668
$\frac{\rho_y}{\rho_u}\cdot\frac{\gamma_u}{\gamma_y}$	.198	.190	.205	.588
Difference betweeh heights (6 and 2)	.08	.10	.10	.10
Difference between widths (F and B)	.95	.95	1.0	.4
Difference between heights (6 and 2) / Difference between widths (F and B)	.084	.105	.10	.25

Table 4 (Pulling velocity, 1/2 m/h)

Beam length	6.1 m	5.3 m	4.5 m	3.8 m
Difference between heights (6 and 2)	.05	.10	.10	.15
Difference between heights (6 and 9)	.10	.10	.20	.20
Total	.15	.20	.30	.35
γ_u	1.00	.75	.50	.43
Height of 7	.60	.65	.70	.70
γ_y	1.00	.92	.86	.86
$\frac{\gamma_u}{\gamma_y}$	1.00	.82	.58	.50
Height of 4 (H)	.60	.58	.70	.70
Width of D (B)	1.5	1.35	1.2	1.2

$\frac{\rho_y}{\rho_u}=\left(\frac{H}{B}\right)^3$	.064	.080	.198	.198
$\frac{\rho_y}{\rho_u}\cdot\frac{\gamma_u}{\gamma_y}$	.064	.066	.115	.099
Difference between heights (6 and 2)	.05	.10	.10	.15
Difference between widths (F and B)	1.3	1.0	1.1	1.1
$\frac{\text{Difference between heights (6 and 2)}}{\text{Difference between widths (F and B)}}$	.039	.10	.091	.136

Table 5 (Pulling velocity, 1 m/h)

Beam length	6.1 m	5.3 m	4.5 m	3.8 m
Difference between heights (6 and 2)	.05	.10	.15	.15
Difference between heights (6 and 9)	.20	.15	.20	.15
Total	.25	.25	.35	.30
γ_u	1.00	1.00	.71	.83
Height of 7	.60	.62	.65	.65
γ_y	1.00	.97	.92	.92
$\frac{\gamma_u}{\gamma_y}$	1.00	1.03	.77	.90
Height of 4 (H)	.55	.63	.63	.60
Width of D (B)	1.3	1.3	1.2	1.2
$\frac{\rho_y}{\rho_u}=\left(\frac{H}{B}\right)^3$	.076	.114	.145	.125
$\frac{\rho_y}{\rho_u}\cdot\frac{\gamma_u}{\gamma_y}$	.076	.117	.112	.113
Difference between heights (6 and 2)	.05	.10	.15	.15
Difference between width (F and B)	1.3	1.2	1.4	1.14
$\frac{\text{Difference between heights (6 and 2)}}{\text{Difference between width (F and B)}}$	.038	.083	.107	.132

m. h. So it may be concluded that the form of the entire bag is merely approximate to an ellips.

The author wishes to express his sincere thanks to Prof., Dr. M. TAUTI of the Tokyo Fisheries University for his kind guidance during this investigation, to Prof. K. ISII for his kind advice, to Mr. Y. YAMAGUTI, and to Mr. I. YOSIMOTO for their assistance during this investigation.

* Including the baiting, the belly and the cod end.

** M. Tauti: Suisan-Buturigaku (Fisheries Physics), 1849, p. 90–95.

No. 1. Nets

A. Baiting: 2.3 cm. mesh, 8 thread cotton netting, 112 mesh deep, 1.2 m. long, 1 piece.

B. Baiting: 2.0 cm. mesh, 6 thread cotton netting, 200 mesh deep, 4.5 m. long, 1 piece.

C. Belly: 6.1 cm. mesh, 3.2 mm. diameter manila twine, 55 mesh deep, 0.85 m. long, 1 piece.

D. Belly: 2.5 cm. mesh, 6 tnread cotton netting, 178 mesh deep, 4.2 m. long, 1 piece.

E. Side: 1.9 cm. mesh, 6 thread cotton netting, 100 mesh deep, 1.5 m. long, 2 pieces.

F. Side: 1.9 cm. mesh, 6 thread cotton netting, 100-90 mesh deep, 0.15 m. long, 2 pieces.

G. Side: 1.9 cm. mesh, 6 thread cotton netting, 47-1 mesh deep, 1.5 m. long 4 pieces.

H. Side: 1.9 cm. mesh, 6 thread cotton netting, 90-1 mesh deep, 1.5 m. long, 2 pieces.

I. Flupper: 2.8 cm. mesh, 6 thread cotton netting, 100 mesh deep, 2.7 m. long, 1 piece.

J. Flupper: 2.8 cm. mesh, 6 thread cotton netting, 100-5 mesh deep, 2.7 m. long, 2 pieces.

K. Cod end: 1.9 cm. mesh, 6 thread cotton netting, 67 mesh deep, 8.1 m. long, 4 pieces.

L. Cod end: 1.5 cm. mesh, 6 thread cotton netting, 133 mesh deep, 2.7 m. long, 1 piece.

M. Cod end: 1.5 cm. mesh, 6 thread cotton netting, 134 mesh deep, 2.9 m. long, 1 piece.

N. Square part: 3 cm. mesh, 6 thread cotton netting, 82 mesh deep, 3 m. long, 1 piece.

O. Wing: 2.3 cm. mesh, 12 thread cotton netting, 90 mesh deep, 0.82 m. long, 2 pieces.

P. Wing: 2.5 cm. mesh, 9 thread cotton netting, 63 mesh deep, 2.7 m. long, 2 pieces.

Q. Wing: 1.9 cm. mesh, 6 thread cotton netting, 100 mesh deep, 3 m. long, 2 pieces.

R. Wing: 2.0 cm. mesh, 9 thread cotton netting, 95-1 mesh deep, 2.1 m. long, 2 pieces.

No. 2. Ropes

Head rope (made from hemp-palm): 4.5 mm. diameter, 8.15 m. long, 1 piece.
Ground rope (made from straw): 19.7 mm. diameter, 11.6 m. long, 2 pieces.
Hand rope (made from manila hemp): 9.1 mm. diameter, 22.7 m. long, 2 pieces.
Warp (made from manila hemp): 9.1 mm. diameter, 15.2 m. long, 1 piece.

No. 3. Floats and Sinkers

Float (made from paulownia): L. 20 cm : B. 6 cm : D. 3 cm : 14 pieces.
Sinker (made from lead): weight, 75 g. 3 pieces. (at bottom.)
(made from earthenware): weight, 225 g. 18 pieces. (at ground rope.)
(made from earthenware): weight, 225 g. 8 pieces. (at plum stave.)
(made from stone) : weight, 4.9 kg. 2 pieces. (at beam.)

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PRELIMINARY REPORT ON EXPERIMENTS WITH SMALL TRAWL NETS

II Change in the height of the Square Part at the mouth of the net with Changes in the Tension of the Rope of the net

(*With 5 figures*)

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Faculty of Fisheries, Prefectural University of Mie

The question of the relationship between the changes of the mouth height of the square part of the net and the tension on the ropes in proportion to different beam lengths and pulling velocities have been studied by means of a small trawl net (6 HP) used in Osaka Bay.

The construction of the net is shown in Fig. 1 of former paper.

The experiments were carried out at Sumoto Bay (depth, 3 meters; bottom character, sand; specific gravity of the sea water, 1.021-1.022). (The

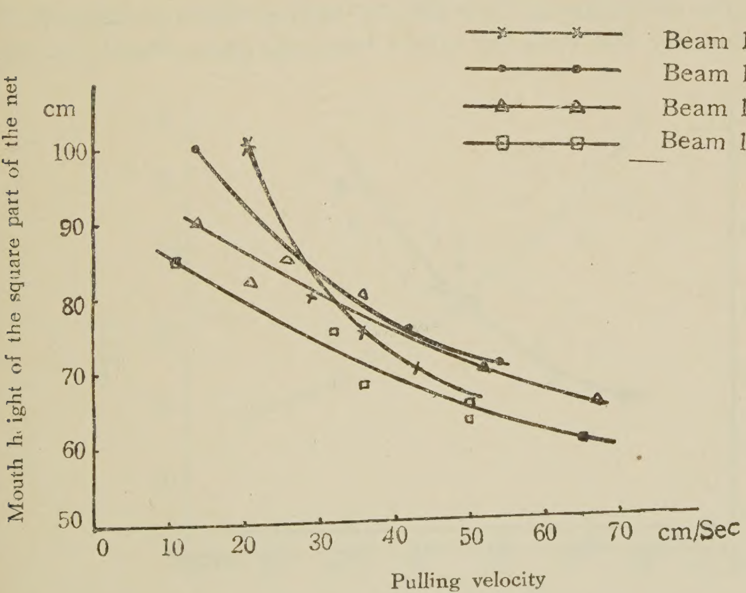

Fig. 1. The relation between the mouth height of the square part of the net and the pulling velocity.

specific gravity of the sea water was measured with AKANUMA's hydrometer.)

The length of the warp was 38 meters, and at a point along the hand ropes 1 meter from the plum staves the beam was attached to hold the mouth of the net in a fixed position.

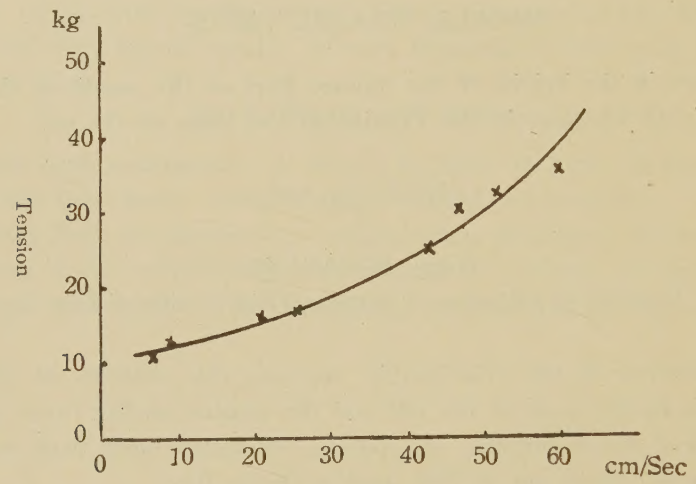

Fig. 2. Beam length, 3.8 m. (favourable current velocity, 0.1 m/h.)

Many test trials were made in this experiment. One set of tests was conducted under the conditions of favorable current velocities of 0.05 and 0.07 m./h. and the trawl net was provided with a beam of 3.8 m. length in some

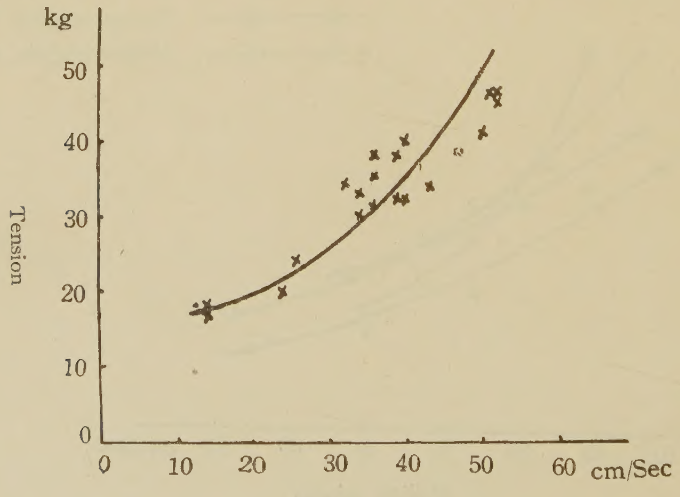

Fig. 3. Beam length, 4.5 m. (stand of tides.)

tests and 4.5 m. length in other tests. The other set of tests was conducted under the conditions of favorable current velocities of 0.2 and 0.19 m./h. and the trawl net provided alternately with a beam of either 5.3 or 6.1 m. length (Fig 1).

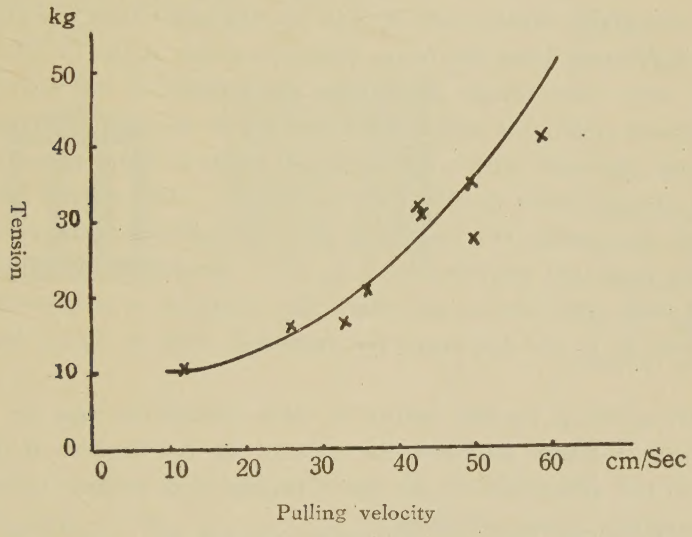

Fig. 4. Beam length, 5.3 m. (favourable current velocity, 0.19 m/h.)

In these tests the pulling velocity was measured by a hand log from the stern of the towing boat.

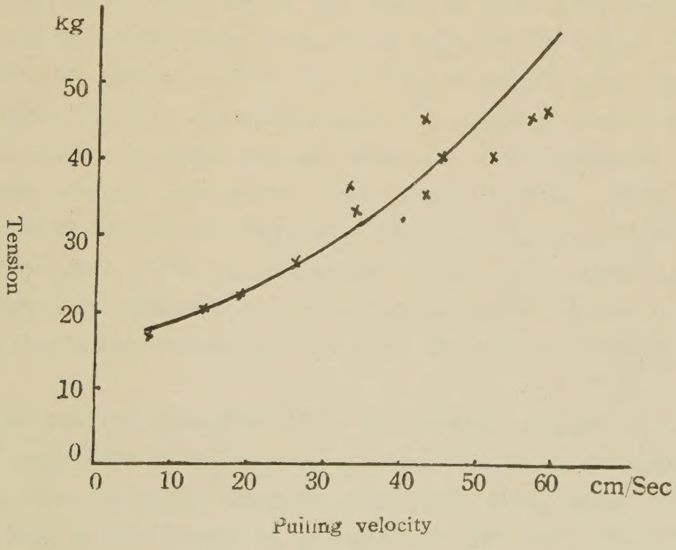

Fig. 5. Beam length, 6.1 m. (stand of tides)

Consideration of the results of the above experiments shows that the mouth heights of the square parts of the nets were not low when the pulling velocity was 1/2 to 1 m./h. and the 4.5 m. length beam was used in the first series of tests, and when the 5.3 m. length beam was used in the second series of tests.

From the above stated fact, it may be concluded that the form of the nets is suited for use when the beam length is either 4.5 m. or 5.3 m.

Many tests were made concerning the tension of the warp. The first set of tests were conducted under the condition of the stand of the tides and the trawl net provided with a 4.5 m. length beam in some tests (Fig. 3) and with a 6.1 m. length beam in other tests (Fig. 5). The second set of tests were carried out under the conditions of a favorable current velocity of 0.1 m./h. and the trawl net provided with a 3.8 m. length beam (Fig. 2). The third set of tests were performed under the condition of a favorable current velocity of 0.19 m./h. and the trawl net provided with a 5.3 m. length beam (Fig. 4).

Further study is needed before a clear conclution can be arrived at concerning the relation between the change of the tension of the warp in proportion to the differences of the beam lengths and pulling velocities with various favorable current velocities.

The author wishes to express his sincerest thanks to Dr. TAUTI for his kind guidance during this investigation, to Mr. Y. YAMAGUTI and to Mr. I. YOSHIMOTO for their assistance during this investigation.